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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

Point and Route Temperatures for Supersonic Aircraft

IRVING I. GRINGORTEN
PAUL TATTELMAN

United States Air Force

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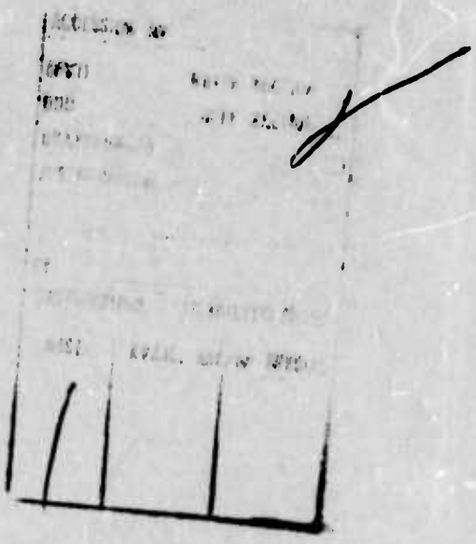

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AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS

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Abstract

This atlas of the northern hemisphere temperature field at SST altitudes consists of 84 plates showing the isotherms at each of the constant-pressure levels, 100, 50, and 30 mb, standard altitudes of 53,000, 67,500 and 78,500 ft, respectively. For each level and season there are seven maps giving the 2-, 10-, 25-, 50-, 75-, 90-, and 98-percentile temperatures. The charts were prepared from twice-daily grid-point data obtained from charts covering the area from the north pole to approximately 15^{o}N for the period 1959 to 1968. Charts were computer analyzed by the Third Weather Wing, Air Weather Service, and made available by the National Weather Records Center, Asheville, N. C.

Since fuel consumption of supersonic aircraft is quite dependent upon temperature, each of the 84 plates is accompanied by a graph giving the probability that the temperatures on any route plotted on the map will equal or exceed the temperatures shown on the map.

While the 84 maps are intended for straightforward informational use in SST flight-planning, there are many noteworthy features that are revealed by the percentile-type presentation. For example, the 96-percent range of temperature is roughly 7^{o} to $10C^{o}$ over the equator but is as great as $35C^{o}$ over the far north in winter, a feature undoubtedly associated with occasional spectacular warmings in the polar stratosphere. But rarely does the temperature increase "explosively." The probability of a $10C^{o}$ 24-hour increase of temperature is less than 10 percent anywhere, even from initially low temperatures. The probability of such increase simultaneously over a wide area, 1000 nm or more, is negligible.

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Point and Route Temperatures for Supersonic Aircraft

I. INTRODUCTION

Design and operation of all supersonic aircraft or the much publicized commercial transport, the SST, are dependent on ambient air temperature at cruising levels of flight (Nelms, 1964; Stickle, 1965). Warm air is a contributing factor towards increased fuel consumption and decreased performance, and compensation must be made by reducing the number of passengers or payload. It is this dependency that has prompted investigations of route temperatures and variability of these temperatures by season and routes and efforts at daily forecasting (Freeman, 1970). More recently, prevention of the sonic boom from reaching the ground has become a problem that makes air temperature, as well as windspeed and direction, a governing factor in the selection of Mach number or ground speed (Haglund, 1970).

Much has been done to provide climatological information on the temperatures at SST levels of 60,000 to 80,000 ft (Crutcher, 1963; Charles, 1964; Court and Abrahms, 1964; FAA-USWB, 1963, 1964a, 1964b; Barr, 1967). But past efforts in this area generally were restricted to preselected routes. Whereas, for Air Force operations, it is important to have available the probable temperatures for any extemporaneous route.

The United States Weather Bureau (USWB) reports have given explicit information on three routes; San Francisco to New York, New York to Paris, and San

(Received for publication 25 June 1970)

Francisco to Stockholm. The Boeing report (Charles, 1964) gives great-circle stratospheric route temperatures that cover the world with some 2300 routes between pairs of some 320 stations. Gringorten (1967) has described a statistical model to derive the frequency distribution of integrated route temperatures on 50- and 30-mb surfaces between any two points over North America and adjacent waters. Crossley (1968) explored the variations on mean route temperatures across the Atlantic.

In addition to the specialized reports referenced above are several climatology reports, mostly mimeographed, with maps or tables of temperature at such levels as 100, 50, 30, and 25 mb (Air Weather Service, 1953, 1960; Hering and Salmela, 1957; Ebdon, 1964, 1965; Goldie, Moore and Austin, 1958; National Weather Records Center, 1966; Crossley, 1968; Ratner, 1957). Other reports have been limited to specific monthly data and are not considered as climatology.

Informative as the above-mentioned reports have been, climatological aspects of the stratospheric temperatures have not been covered in sufficient detail. For greater usefulness, the charts should be global or hemispheric in coverage and should show percentiles to cover 95 percent or more of the range of temperatures at several key levels. Utilization of means and standard deviations provided in several reports for obtaining frequency distributions is based on the assumption that the distribution of the temperature is Gaussian or normal – an assumption whose validity is significantly curtailed by the bimodality of temperature in the northern latitudes, especially in the winter months.

Plates 1 through 84 of this report present temperatures from the north pole to, roughly, 15°N latitude, at levels 100, 50 and 30 mb. For each level and season there are 2-, 10-, 25-, 50-, 75-, 90-, and 98-percentile maps. Each chart is accompanied by a graph showing the probability that temperatures along a given route classified by its route length and mid-latitude will exceed all the temperatures shown by the chart along the route. This is not the same as the probability of the average of these route temperatures. There is evidence, however, that such an average, when further averaged with the average temperature on the 98-percentile chart, will yield a satisfactory approximation of the true average route temperature distribution. However, an average temperature for an entire route is only one method of treating the temperature problem and may not be the best method.

This report treats only the temperature. The extent that route winds should be presented jointly with temperature (Crossley, 1969) has not been considered in this report.

2. DATA SOURCES

The investigation in this report had its start upon receipt of an announcement from the Environmental Scientific Services Administration (ESSA) dated 24 Aug 1966, that "a special series of (daily) stratospheric constant-pressure charts has been produced in connection with the project IQSY (International Quiet Sun Year) in the years 1964, 1965" (ESSA, 1967). The announcement stated, "The analyses have been performed for the Northern Hemisphere with 1977 grid points bounded by an octagon near the 15°N latitude circle," and further stated that "height and temperature values for each point on the 1977-point grid are available on magnetic tape." Such synoptic records, presented at each point of a rectangular grid on a polar stereographic projection of the northern hemisphere, is precisely the kind of information that can be treated to give (1) temperature frequency distribution at points that systematically cover the hemisphere, and (2) the probability of exceeding threshold temperatures along any route across the hemisphere. Also, the presentation of temperature on constant-pressure surfaces is particularly relevant, since aircraft flying at constant pressure altitude fly on such a surface.

The rectangular grid had its beginnings in earlier efforts. For Project 433L (FAA-DOD, Dept. of Commerce, 1959) an evenly spaced grid was superimposed on the polar stereographic projection, with center point over the north pole, and axes aligned with the meridians of longitude 10°E - 170°W and 100°E - 80°W. On a map of scale 1:15,000,000 at latitude 60°N, the grid interval was exactly one inch in both directions. This same grid, limited to the 1977 points that form an octagon whose center is at the north pole, had been used for the IQSY tapes.

For any standard upper air sounding time and level, say 1200Z on Jan 1959 at 100 mb, world-wide radiosonde and other supporting data, such as upper winds and surface temperatures and pressures, provide enough basic information which, by subjective or objective procedure, whether or not inserted by cards and magnetic tapes into computing machines, will lead to an analysis of the upper-air hemispheric synoptic temperature field. The 1977 grid-point data are the result of computer procedures and analyses, including methods of least squares and interpolation of the basic data. A method based on the experimental results of Gilchrist and Cressman (1954) and others was used at tropospheric levels to interpolate between observed values and to make the best estimates of the synoptic values at each of the 1977 grid points.

Bergthorsson and Doos (1955) have cautioned that the objective method of analysis must be weak over oceanic areas where synoptic data are scarce and over the equator, around the periphery of the chart. The methods of analysis begin with climatically normal values in areas of sparse data, which values are slowly modified by infrequent synoptic data from map to map. Forecasted values are also used

at grid points where synoptic input data do not reach or do not contribute significantly to the interpolation and estimation of the grid-point values. Over ocean areas, the surface ship observations are used to extrapolate contour heights and temperatures to upper levels (Doos and Eaton, 1957).

The preceding paragraph very slightly describes the procedure that has been used to produce analyzed synoptic values at the 1977 grid points at tropospheric levels like 700 and 500 mb. Finger, Woolf and Anderson (1965) have described essentially the same technique applied to stratospheric constant-pressure charts. Additionally, they describe many factors that enter into the final analysis and printing of the grid-point data including data error checks, vertical extrapolation of temperature and height, the incorporation of wind information including off-level winds, and the corrections for radiational effects on instruments including solar radiation.

Though beginning with ESSA's IQSY data, it was recognized that two years of record (1964, 1965) were not enough for a satisfactory climatology of stratospheric temperatures, especially since a 2-year cycle has been discovered in the weather elements (Angell and Korshover, 1962; Shah and Godson, 1966; Reed et al, 1963) and the stratospheric warming in the winter months at high latitudes is an irregular and infrequent phenomenon (Craig and Hering, 1959; Engberg and Belmont, 1964; Finger and Teweles, 1964; Johnson, 1969; Johnson and Gelman, 1968).

Later, attention was directed to the twice-daily synoptic charts at times 0000Z and 1200Z, that are drawn of constant-pressure surfaces by the Climatology Branch, Aerospace Sciences Div., Hq. Third Weather Wing, (3WW) AWS. These charts are analyzed and recorded on magnetic tapes at the same 1977 grid points as on the ESSA tapes. The objective computer program, while similar to the ESSA program, is somewhat different and produces a different set of analyzed charts making it inadvisable to mix the charts or tapes from the two sources. The AWS tapes for the 100-mb surface, beginning with April 1959 and continuing through May 1968, were made available by the National Weather Records Center through the Environmental Technical Applications Center (ETAC). For the 50- and 30-mb surfaces, magnetic tapes have been provided to cover the twice-daily temperature observations from 1 Jan 1962 to 29 Feb 1968.

Before concluding this section on data sources, some consideration must be given to the errors in the observations of temperature at the SST levels. Several reports, 8 to 13 years ago, (Badgeley, 1957; Chiu, 1959; Ney et al., 1961; Harris, et al., 1962) discussed the errors due to the lag of the temperature sensors as the balloon rises, and the radiational absorption and emission of the instrument package which will show up as a difference between daytime and nighttime readings. The latter was considered to be the more significant error, increasing with height. In the past 10 years, the United States radiosondes have been improved to reduce

this source of error, but there is a problem with observations taken by many countries over the northern hemisphere.

Roache (1964) has written that the total of sensor and system errors are within ±2C°. In the United States, since 1960, the mean daily range is 1.5C° at 50 mb. But in other countries throughout the northern hemisphere, the diurnal effect at 50 mb may cause errors exceeding 5C°. Hintzpeter (1968) has felt compelled to doubt the world-wide compatibility in synoptic analysis of higher atmospheric levels, owing to differences in instrumentation.

The pessimism with regard to instrumentation and observation is offset by the fact that the synoptic maps that have been used for this study have been analyzed to eliminate suspected data and to synthesize the acceptable data in viable synoptic situations. The effect of the relatively large rms error of 2C° at a single location should have little or no effect on its median value and will tend to overestimate the upper and lower 2-percentile by roughly 1C° to 0.2C° depending on the variability corresponding to standard deviations of 3 to 10C°. But the effect on route temperatures is to underestimate the horizontal persistence of warm air enroute (see Section 5). It is difficult to estimate the importance of this effect; it remains an open question.

3. PROCESSING CONSTANT – PRESSURE GRID – POINT DATA

The 1977-point grid, considered too dense for this effort, is reduced by selecting the points in every other row and every other column, thereby reducing the grid to 491 points located on 25 rows and 23 columns (Figure 1). The octagon shape is retained with its perimeter approximately at latitude 15°N. Using the symbol I for the column number and J for the row number, the first point becomes (I=7, J=1), the north pole has coordinates (I=12, J=13), the last point is (I=17, J=25). The first row (J=1) extends from southern India to the Philippines. The middle row (J=13) extends from northern Africa through the north pole to the 20th parallel in the Pacific Ocean. The last row (J=25) begins just north of South America and crosses Central America into the Pacific. If the middle row (J=13) is considered the X-axis, then the middle column (I=12) is considered the Y-axis.

The data, twice daily on the 100-mb surface, at each of the 491 points, from 1 April 1959 through 31 May 1968, should contain 1626 wintertime synoptic values of temperature at each of the 491 grid points. Actually there are 1581 winter maps in the sample. Likewise, the spring sample consists of 1691 maps instead of 1778 maps, the summer sample is 1606 instead of 1656, and the autumn sample is 1517 instead of 1638. The eliminated maps either had missing data or contained values higher than -20°C or lower than -99°C at one or more grid points. It was soon

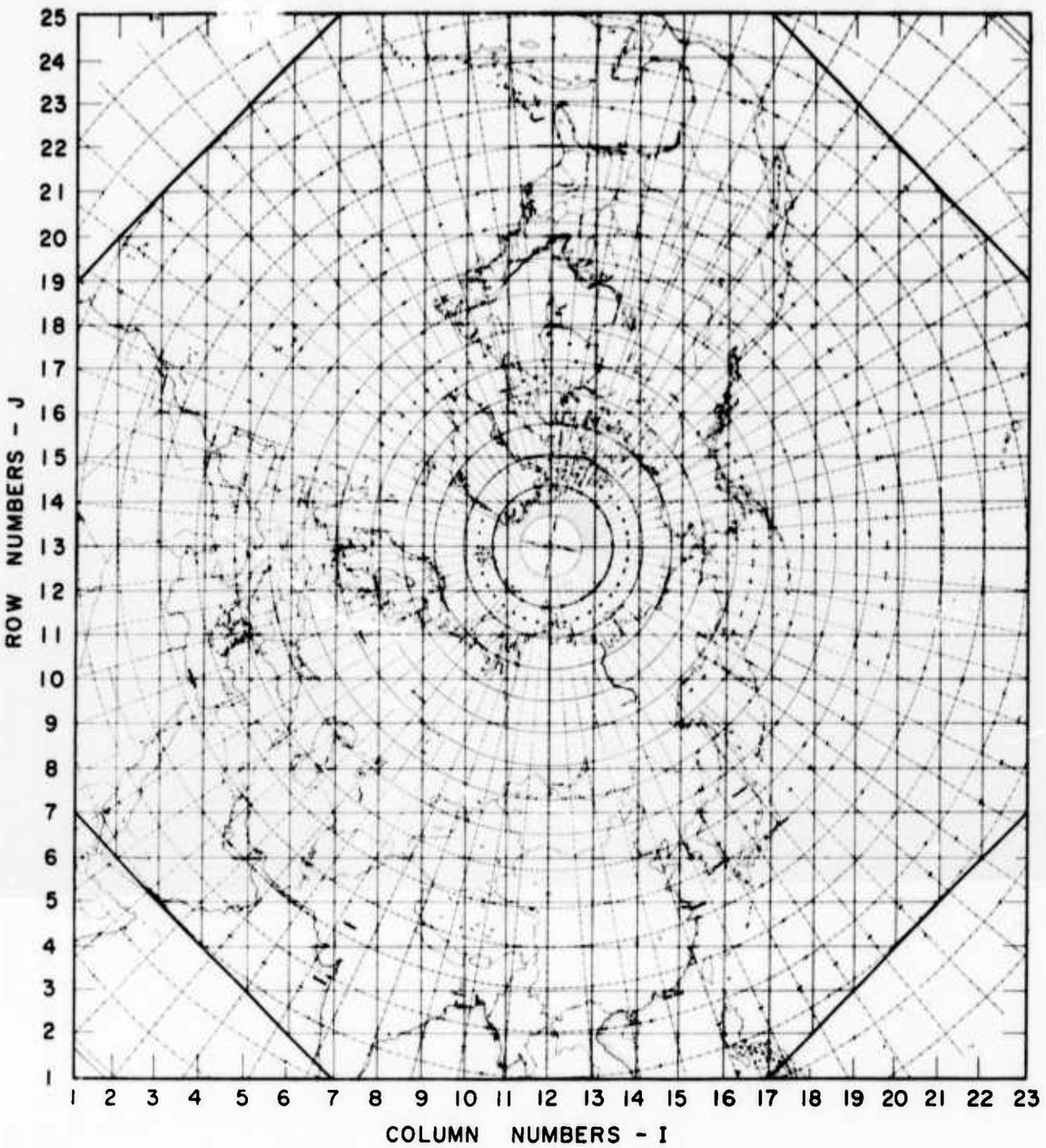

Figure 1. The 491-point Grid Covering the Northern Hemisphere From the North Pole at its Center to Approximately 15°N at its Periphery. On a scale of 1:30 million the grid points are 1 inch apart in rows and columns

learned that, through occasional errors in storing the data on tapes, the latter would contain incomprehensible records and hence needed to be eliminated from the sample. Such errors usually affected isolated maps in the record, but there were also months with frequent errors, mainly Dec 1961, Sept 1963, and Sept 1965. Such sources of error could not be traced. The maps that were retained in the

sample were accepted as reasonably accurate except for the peculiarities described in the following paragraphs.

As a further check on the data, each monthly average chart was computed for all grid points and printed. The data of the 100-mb averaged maps, Feb 1962 and March 1962, became suspect in the upper left-hand corner, affecting columns (I=1 and 2) and rows (J=16 to 21). To examine them further, the grid-point temperatures of the 56 synoptic maps of Feb 1962 were printed. It was soon realized that the error centered on the printed temperature at (I=2, J=20). For 1 to 3 Feb 1962, this temperature was reasonable. But, beginning with 4 Feb 1962, and into March 1962, the temperature at (I=2, J=20) increased from -80°C to much higher unwarranted values. Adjacent values must have been affected through the computerized system of analysis. In the overall sample of winter and spring maps, this error affects the lower 5 percent of the distribution of temperatures in the vicinity of (I=2, J=20). It was decided, therefore, to correct the ultimate 2-percentile charts of the winter and spring temperature field instead of eliminating the 122-odd maps of February and March 1962.

There was still another suspected problem at the left-hand periphery of the 100-mb winter and spring maps. For northern Africa, a narrow tongue of warm air extended toward the equator. That peculiarity was due to suspiciously high temperatures during the five months beginning with October 1961. The suspected effect was bad in the Dec 1961 monthly average, worse in Jan 1962, worst in Feb 1962, and almost as bad in March 1962. But the mean monthly map of April 1962 looked normal. The 56 synoptic maps of Feb 1962 were again examined and compared with the USWB Northern Hemisphere Data Tabulations for three North African stations: Niamey (13° 29'N, 2° 10'E), Fort Trinquet (25° 14'N, 11° 37'W), and Dakar (14° 40'N, 17° 26'W). The conclusion reached was that for the suspected months in the 1961-62 season, the temperatures on the tapes were too high by 8 to 10C° in the vicinity of Niamey, reasonably correct at Fort Trinquet, and too high by 3 to 5C° at Dakar. Again, since these errors were at the periphery of the octagonal grid, the maps were not eliminated because the error could be eliminated in the subsequent drawing of the upper percentile charts.

Since the AWS magnetic-tape grid-point data extended southward only to 15 or 20°N, it was decided to supplement, at least, the 50-percentile charts with the information on the mean temperatures at seven tropical stations (see Table 1). This provided some guidance on the drawing of the isotherms on the other percentile charts, to extend them toward the equator.

The set of 50-mb charts was similar to the set of 100-mb charts in the losses due to errors of coding. In fact, the list of eliminated charts read almost the same as for the 100-mb charts. But there was one peculiarity in the peripheral analysis: a spurious center of low temperatures over the China mainland, south of

Table 1. Seasonal 100-mb Mean Temperatures (^{o}C) Over Selected Subtropical Stations

Station	Latitude	Longitude	Summer	Autumn	Winter	Spring
Lihue, T. H.	21^{o} 59'N	159^{o} 21'W	-70	-73	-75	-72
Wake Is	19^{o} 17'N	166^{o} 39'W	-73	-77	-81	-77
Johnston Is	16^{o} 44'N	169^{o} 31'W	-73	-75	-78	-76
Clark AFB	15^{o} 10'N	120^{o} 34'E	-78	-80	-80	-79
Eniwetok Atol	11^{o} 20'N	162^{o} 20'E	-76	-79	-82	-80
Balboa, C. Z.	8^{o} 56'N	79^{o} 34'W	-76	-78	-80	-79
Canton Is	2^{o} 46'S	171^{o} 43'W	-80	-81	-83	-82

Parallel 40^{o}N. Here, the previously analyzed USWB IQSY charts provided guidance in correcting the drawing of the percentile charts. No charts were eliminated on account of this suspected error, but simply corrected.

Ironically, the 30-mb charts had no large suspected errors. The most plausible explanation is that the temperature field, in the subtropical and equatorial latitudes, where the suspected and persisting errors occurred at levels 50 and 100-mb, is undisturbedly uniform and flat at the level of 30 mb, remaining steadily between -51^{o}C and -59^{o}C.

In spite of the losses and gaps in the record, there was some fear that the computing process might require excessive machine time. Careful and inventive planning by the computer programmers, however, finally permitted the use of all the data without elimination of any usable data.

4. PERCENTILE TEMPERATURE MAPS (Plates 1 to 84)

The computing facility sorted 12-hourly temperatures for each grid station (I, J) by altitude (100 mb, 50 mb, 30 mb) and season (winter, spring, summer, autumn) in order to find the 2-, 10-, 25-, 50-, 75-, 90-, and 98-percentile values. Printouts of these percentiles, beginning with the 2-percentile of each grid point, were printed at proper relative locations, the grid spacing fixed by the printer at one inch. Since the computing-machine paper is only large enough for the printing of 9 rows and 12 columns, six such sheets were required for the printing of one full chart to cover the northern hemisphere as far south as 15^{o}N. These sheets were assembled, taped or cemented together, six to each percentile chart, and isotherms were drawn.

Recalling that the original grid spacing was one inch, thereby fitting a polar stereographic chart of a scale 1:15,000,000 at latitude 60°N, the above-described assembled charts, composed of every other row and column set one inch apart, must fit onto a polar stereographic map, scale 1:30,000,000. Hence, it was a simple procedure to copy the analysis of each percentile chart onto a polar stereographic base-map of the northern hemisphere, scale 1:30,000,000 at 60°N. Plates 1 to 84 are the result. Through photographic reduction, the scale of these maps in this report becomes 1:108,000,000.

The scale (1:30,000,000) of the working chart is such that one inch represents 411.25 nm at latitude 60°N. One inch centered at any latitude ϕ represents

$$220.4\ (1 + \sin\phi)\ \text{nm}.$$

For this study, it was desired to find roughly the mileage covered by 3, 6, and 12 grid points along a row or a column. The above formula for the spacing of grid points provided the route lengths (nm) of Table 2.

Table 2. The Distance Covered by 3, 6, and 12 Consecutive Grid Points Along a Row or Column

Mid-latitude	3 points	6 points	12 points
80-90°N	880 nm	2200 nm	4840 nm
70-79	866	2165	4763
60-69	840	2100	4620
50-59	802	2005	4411
40-49	752	1880	4136
30-39	694	1735	3817
20-29	628	1570	3454
15-19	538	1345	2959

4.1 100-mb Surface – Standard Altitude 53,000 ft. or 16.2 km

Many interesting features are worth examining. The winter air is coldest over the equatorial belt in the -80's C, and is also relatively cold over the polar regions in the -70's. There is a warm belt circling the hemisphere between latitudes 40° and 60°N, with a highly persistent warm center west of the Aleutian chain that remains between -55°C and -41°C.

The map of median or 50-percentiles should look familiar to anyone who has studied isotherms of averages. These middle values range from -82°C over the

equatorial regions up to -48°C west of the Aleutian chain. The cold center over the north pole is pronounced. Turning to the upper 2 percent of the temperatures, the effects of stratospheric warming are noticeable. Warm air in the -40's can cover almost any region north of latitude 50°N. It must be remembered that these are not simultaneous values. To what horizontal extent a single warm condition prevails is discussed below.

The summer charts display a more understandable symmetry, with the coldest air over the equator and warm center over the north pole.

4.2 50-mb Surface – Standard Altitude 67,500 ft. or 20.6 km

The isothermal field is generally flatter on the 50-mb charts than on the 100-mb charts, primarily because the 50-mb surface is well above the equatorial tropopause. In winter, at low latitudes, the temperature ranges from -70°C to -62°C. The air is coldest near the north pole, ranging from -82°C to -68°C. The warm belt is much less distinct; it centers on latitude 55°N and features a warm center that has shifted westward toward the Kamchatka Peninsula, with temperatures ranging from -57°C to -39°C. In summer, at low latitudes, the 50-mb temperatures are almost uniform, ranging between -65°C and -60°C. The air is the warmest over the north pole, between -46°C and -36°C.

4.3 30-mb Surface – Standard Altitude 78,500 ft. or 23.85 km

The flattening of the temperature field over tropical and equatorial regions is still more pronounced at this level than at the 50-mb level, causing the warm belt of wintertime to nearly disappear, but the patterns over the polar regions (cold in winter, warm in summer) are generally pronounced. The lowest temperature in winter is -84°C, but over the Kamchatka Peninsula the upper 2-percentile is -35°C, the warmest on any of the 84 charts of this report. In summer, the warm polar center has an upper 2-percentile temperature of -37°C.

4.4 Temperature Extremes and Ranges

Table 3 illustrates some highlights of the temperature field as they might affect long-range SST flight. In any one season, the horizontal range of temperature is of the order of 45C° on the 100-mb surface, almost the same on the 50-mb surface, and 49C° on the 30-mb surface. Over the equator, the air is coldest at the tropopause near 100 mb and warms up with increasing elevation, and the seasonal range at a single level remains under 12C°. In the warm belt, and particularly at the warmest point in the belt, the temperature range is small but increases with altitude as the belt becomes less distinct.

Table 3. The Annual Low (2 percent), the Annual High (98 percent), and the Seasonal Range (96 percent) of Temperature (°C)

	100 mb			50 mb			30 mb		
	low	high	range	low	high	range	low	high	range
Hemispheric	-86	-38	45	-82	-36	43	-84	-35	49
Equatorial	-86	-68	12	-70	-58	9	-60	-51	8
Warmest Point	-57	-41	16	-59	-39	20	-62	-35	27
North Pole	-74	-38	31	-79	-36	32	-80	-38	33

5. HORIZONTAL PERSISTENCE

By computer technique, it was possible to find the frequency, in each season at each level, with which the p-percentiles (p = 0.02 to 0.98) of temperature at each of n consecutive grid stations along a row or column are equalled or exceeded. This was done, and the frequencies were classified by mid-latitude. For example, for the 100-mb level, wintertime 2-percentile chart (Plate 1), the frequencies with which the temperatures equalled or exceeded the temperatures as read on the chart at 3, 6, or 12 consecutive grid stations in a row are shown in Table 4a. The frequencies of exceeding the temperatures on the same chart at 3, 6, or 12 consecutive grid stations in a column are shown in Table 4b. These frequencies must be considered under-estimates if there are substantial errors in the synoptic data (see Section 2).

There was a satisfying similarity of these frequencies in rows and columns classified by mid-latitude which suggests that the probability of exceeding the temperatures that appear along a route on a single map is independent of the orientation of that route. The root mean square difference (rmsd) of such probabilities was roughly 0.0085 in winter, 0.016 in summer, 0.020 in spring, and 0.027 in autumn. The overall rmsd is 0.019. The frequency, or probability, of exceeding the temperatures shown along a route did not seem to be a function of longitude, as long as the mid-latitude of the route was in a given 10-degree belt. The rms departure of the probability on any single route from the indicated frequency was 0.024. Suppose, now, that a graph is composed of the averages of corresponding figures in Tables 4a and 4b. Then, the probability of temperatures which are equal to or which exceed the route temperatures on any p-percentile chart as a function of route length and mid-latitude would be in error by a rmsd of approximately

$$\sqrt{(.024)^2 + (0.019/2)^2} = 0.03.$$

Table 4a. Frequency With Which the 2-percentile Temperatures Are Exceeded Consecutively Over 3, 6, and 12 Grid Points in a Row

mid-latitude	3 points	6 points	12 points
0 to 20°N	0.98	0.96	0.93
21 to 30	0.97	0.95	0.91
31 to 40	0.97	0.94	0.89
41 to 50	0.96	0.93	0.89
51 to 60	0.96	0.93	0.88
61 to 70	0.94	0.93	0.88
71 to 80	0.94	0.94	0.88
81 to 90	0.97	0.93	0.88

Table 4b. Frequency With Which the 2-percentile Temperatures Are Exceeded Consecutively Over 3, 6, and 12 Grid Points in a Column

mid-latitude	3 points	6 points	12 points
0 to 20°N	0.98	0.96	0.94
21 to 30	0.97	0.96	0.92
31 to 40	0.97	0.95	0.91
41 to 50	0.97	0.95	0.90
51 to 60	0.97	0.95	0.90
61 to 70	0.97	0.94	0.90
71 to 80	0.97	0.94	0.89
81 to 90	0.97	0.95	0.89

Each of the graphs facing Plates 1 to 84 was plotted by averaging the figures in pairs of printouts resembling Tables 4a and 4b. The route lengths were those of Table 2 for the distances covered by 3, 6, and 12 grid points. Isopleths of equal probability are drawn on the graphs whose rms error of estimate is accepted at 0.03.

Each northern hemisphere map (Plates 1 to 84) is a percentile chart and not a synoptic chart. In Plate 7, for example, over the Indian Ocean the temperature of -68°C does not necessarily occur at the same time as the temperature of -43°C over Eastern Siberia. More likely, such high extremes will occur at different times. The use of these northern hemisphere maps is made to obtain a measure of horizontal persistence upon which the graphs opposite each plate were prepared. Graph No. 4 accompanies Plate No. 4 of the 100-mb 50-percentile winter map, and

shows that if the temperature is median over any given point in flight, it should remain median, or higher, for about 500 miles, after which the probability of the same or higher temperatures, continuously along the flight path, drops rapidly with increasing path length. For a 5000-mile trip there is only a 5-percent chance of all temperatures exceeding the medians along the route. This result is similar for any altitude and any season. The greater persistence, generally, is for the higher latitudes. Turning to the upper 98-percentile (Plate 7 and Graph 7), if there is a high temperature over one checkpoint of the flight, the temperature will remain high for, at the most, 500 miles. The probability of persistently high temperature becomes negligible with increasing trip length.

6. ESTIMATING ROUTE AVERAGE TEMPERATURE DISTRIBUTION

Each of Graphs 1 to 84 gives the probability with which temperatures along a route of given length and mid-latitude equal or exceed those showing on the map. This information falls short of answering the more obvious question: what is the likelihood that the average route temperature will exceed a critical value? An arbitrary procedure is adopted in the following paragraph to make an estimate.

The procedure, illustrated on the route between New York and San Francisco, winter, 100-mb (Table 5) calls for averaging the temperatures shown in each of the Plates 1 to 7 along the route and then further averaging with the route average on the 98-percentile plate. Each of Graphs 1 to 7 at route length (2230 nm) and mid-latitude (40^{o}N), provides a probability figure which is also recorded (Column 3, Table 5). This is the probability that the temperature will be higher than those shown on the map, and it seems reasonable that the route average temperature, further averaged with the warmest route temperatures (98 percent), will come close to the mean route temperature at that probability level. Column 4, Table 5 shows, for comparison, the temperatures given by the FAA (1963) study, at the same frequency levels, from direct sampling of the average route temperature on a set of winter synoptic charts (1957 to 1962). Figure 2 shows the plot of the temperatures of Column (2) versus the probability of Column (3). The summer curve is also plotted in Figure 2 and shows, surprisingly, that the 100-mb summer temperatures are slightly lower than the winter temperatures, thereby offering a slight advantage in summer to SST performance along the New York to San Francisco route.

Tables 6, 7, and 8 take advantage of the three FAA-USWB reports (1963, 1964a, and 1964b) to determine how well the estimates of route-average upper percentiles, by the method of this report, compare with estimates by direct sampling. On the 100-mb surface (Table 6), the rmsd is 1.0C^{o}, and the mean bias is 0.7C^{o} for the estimates at the 2-percent and 10-percent levels of risk. On the 50-mb surface

Table 5. San Francisco to New York 100-mb Winter Route Average Temperature Distribution. Column (1) gives the average temperature from Plates 1 to 7. Column (2) gives these averages further averaged with the 98-percentile average. Column (3) gives the cumulative probability as read from Graphs 1 to 7 for route length 2230 nm, mid-latitude 40°N. Column (4) gives the route average as determined from the FAA (1963) study for comparison with Column (2)

Percentile	(1)	(2)	(3)	(4)
.02	-68.4°C	-60.8°C	.94	-63°C
.10	-65.1	-59.2	.74	-61
.25	-63.4	-58.4	.47	-59
.50	-60.1	-56.7	.17	-57
.75	-58.0	-55.7	.06	-55
.90	-55.4	-54.4	.012	-54
.98	-53.3	-53.3		-53

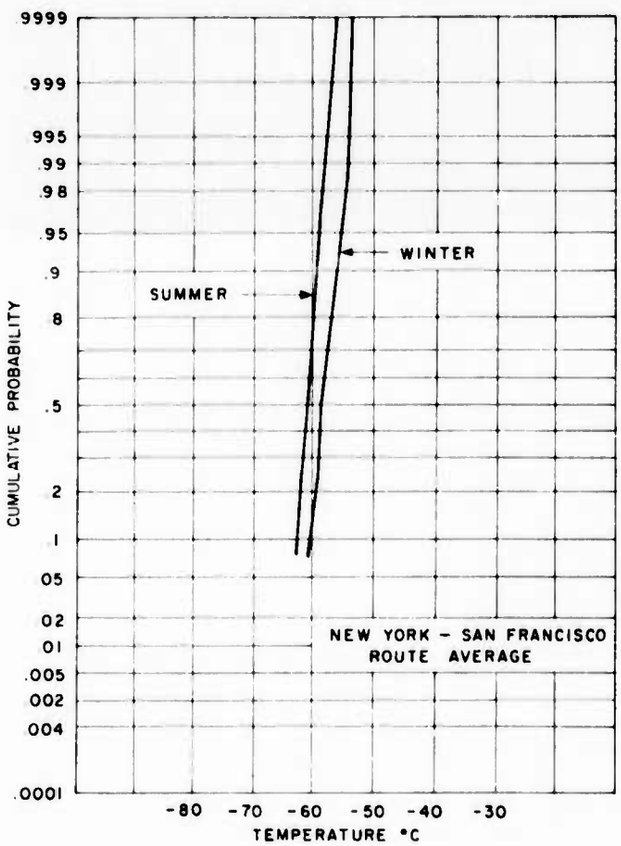

Figure 2. The Probability Distribution of the Route Average Temperature, New York to San Francisco, at the 100-mb Level, Winter and Summer Compared

Table 6. Comparison of Estimates of the 2- and 10-percentiles of Average Route Temperatures on 100-mb Surface, All Four Seasons, by FAA-USWB Using 1957 to 1962 Data, and by AFCRL Method Which is Based on 1957 to 1968 Data. Route (1) is Paris to New York, Route (2) is New York to San Francisco, Route (3) is San Francisco to Stockholm

Season	Percentile	Study	Route		
			(1)	(2)	(3)
Winter	2%	FAA	-51	-54	-50
		AFCRL	-52	-55	-52
	10%	FAA	-53	-56	-53
		AFCRL	-54	-56	-54
Spring	2%	FAA	-49	-54	-46
		AFCRL	-51	-55	-47
	10%	FAA	-51	-56	-47
		AFCRL	-51	-56	-48
Summer	2%	FAA	-50	-59	-45
		AFCRL	-51	-59	-47
	10%	FAA	-51	-60	-46
		AFCRL	-52	-60	-47
Autumn	2%	FAA	-53	-58	-49
		AFCRL	-53	-58	-50
	10%	FAA	-55	-60	-50
		AFCRL	-55	-60	-51

(Table 7), the rmsd is 1.2C^{o}, and the mean bias is 0.8C^{o}. On the 30-mb surface (Table 8), the rmsd is 1.4C^{o}, and the mean bias is 0.9C^{o}.

7. PROBABILITIES OF WARMING

Occasionally, the stratospheric warming of winter has been spectacular. In a survey (Engberg and Belmont, 1964) of radiosonde observations at six northern stations in the years 1956 to 1960, the extreme 24-hour warming at 20 km was 17C^{o}. But the so-called explosive warming usually is spread over several days or even several weeks. Recently Quiroz (1969) described a case of exceptional warming in 1966, which placed the most intense rise of temperature well above the presently intended levels of SST. Finger and McInturff (1970) reviewed the event on Jan 1968, revealing that the temperature at 20 km rose 30C^{o} in a 4-day period.

Table 7. Comparison of Estimates of the 2- and 10-percentiles of Average Route Temperatures on 50-mb Surface by FAA-USWB Using 1957 to 1962 Data and by AFCRL Method Which is Based on 1962 to 1968 Data. Route (1) is Paris to New York, Route (2) is New York to San Francisco, Route (3) is San Francisco to Stockholm

Season	Percentile	Study	Route		
			(1)	(2)	(3)
Winter	2%	FAA	-49	-54	-51
		AFCRL	-51	-54	-52
	10%	FAA	-52	-55	-55
		AFCRL	-53	-55	-55
Spring	2%	FAA	-49	-52	-46
		AFCRL	-50	-53	-46
	10%	FAA	-51	-54	-47
		AFCRL	-51	-54	-47
Summer	2%	FAA	-47	-52	-44
		AFCRL	-49	-52	-46
	10%	FAA	-48	-53	-45
		AFCRL	-50	-53	-46
Autumn	2%	FAA	-50	-53	-44
		AFCRL	-52	-54	-46
	10%	FAA	-52	-54	-50
		AFCRL	-53	-54	-52

There also was an instance of a 50C^{o} rise in a few days at the 30-km level. Between the dates of 6 Dec 1967 and 10 Jan 1968 (Johnson, 1969; ESSA, 1969) at 30 km, there was a 45C^{o} rise over northern Greenland, and a 65C^{o} rise (-55 to 10^{o}C) over northern Alaska from 6 Dec to 27 Dec 1967 at the 40-km level.

But the question faced herein is: Given the present temperature to what value will it increase in 24 hours? The Canadian radiosonde synoptic data for the 1967 to 1968 case were examined, and the extremes of Table 9 were found. Recognizing that such increases are isolated cases, the next step was to estimate the <u>risk</u> of sudden warmings. A statistical survey was made to give a fairly complete result on 24-hour changes of temperature on the 100-, 50-, and 30-mb levels (Table 10). Beginning with the lowest temperatures (2 percent), the 24-hour increase was no more than 10C^{o} with 90-percent certainty. Beginning with the median temperatures, the 24-hour increase was under 8C^{o} everywhere, with the same 90-percent probability. Beginning with a high temperature (98 percent) the probability of

Table 8. Comparison of Estimates of the 2- and 10-percentiles of Average Route Temperatures on 30-mb Surface by FAA-USWB Using 1957 to 1962 Data and by AFCRL Method Which is Based on 1962 to 1968 Data. Route (1) is Paris to New York, Route (2) is New York to San Francisco, Route (3) is San Francisco to Stockholm

Season	Percentile	Study	Route		
			(1)	(2)	(3)
Winter	2%	FAA	-45	-50	-52
		AFCRL	-49	-51	-52
	10%	FAA	-52	-52	-57
		AFCRL	-52	-54	-55
Spring	2%	FAA	-47	-47	-45
		AFCRL	-48	-49	-45
	10%	FAA	-49	-49	-46
		AFCRL	-49	-49	-46
Summer	2%	FAA	-43	-46	-42
		AFCRL	-45	-47	-43
	10%	FAA	-44	-47	-43
		AFCRL	-46	-48	-43
Autumn	2%	FAA	-47	-48	-48
		AFCRL	-49	-49	-49
	10%	FAA	-50	-49	-51
		AFCRL	-50	-49	-51

additional temperature rise, by more than 3C° is negligible except for 7C° rise in winter over northern Siberia. (There is supporting evidence on the 24-hour changes by Olintsava and Uranova, 1968, and by Crossley, 1969.)

With regard to route averages, an extensive computer study did not yield any significant risk of an abrupt rise on any route exceeding 500 nm in length.

Table 9. Some 24-hour Increases of Temperature During the Stratospheric Warming Incident of December 1967

Place	Height	Time Interval	Increase
Stephenville, Nfdld.	30 mb	26-27 Dec	15C° from -55 to -39°C
Maniwaki, Que.	30 mb	26-27 Dec	15C° from -55 to -40°C
Nitchequon, Que.	30 mb	27-28 Dec	13C° from -45 to -32°C
Moosonee, Ont.	20 mb	27 Dec	Temperature reached -19°C
Fort Chimo, Que.	20 mb	27-28 Dec	27C° from -46 to -19°C
	30 mb	27-28 Dec	20C° from -52 to -32°C
	50 mb	27-28 Dec	12C° from -66 to -54°C
Frobischer Bay, NWT	30 mb	28-29 Dec	22C° from -58 to -36°C
Hall Beach, NWT	20 mb	28-29 Dec	22C° from -68 to -46°C
	30 mb	28-29 Dec	10C° from -69 to -59°C
Clyde, NWT	30 mb	28-29 Dec	18C° from -65 to -47°C
Resolute, NWT	20, 30 mb	any time	less than 10C° with low temperatures
Eureka, NWT	10 mb	29-30 Dec	24C°
	20 mb	28-29 Dec	16C°
	30 mb	28-29 Dec	7C°
Alert, NWT	10 mb	28-29 Dec	27C° from -57 to -30°C
	20 mb	29-30 Dec	18C° from -61 to -43°C
	30 mb	29-30 Dec	9C° from -66 to -57°C

Table 10. The 10-percent Risk of the Local 24-hour Temperature Increase, in the Northern Hemisphere, Above the Temperature of the Indicated Percentile Chart

	100-mb percentile chart						
Season	.02	.10	.25	.50	.75	.90	.98
Winter	4 to 9	1 to 6	1 to 5	2 to 4	2 to 3	2	0 to 2C°
Spring	3 to 6	1 to 5	1 to 4	1 to 2	0 to 1	0 to 1	0 to 1
Summer	3 to 6	2 to 5	0 to 5	0 to 3	0 to 2	0 to 1	0 to 1
Autumn	5 to 7	2 to 5	1 to 5	1 to 3	1 to 2	0 to 2	0 to 2
	50-mb percentile chart						
Season	.02	.10	.25	.50	.75	.90	.98
Winter	1 to 7	1 to 6	1 to 7	1 to 6	1 to 6	1 to 4	-2 to 3C°
Spring	2 to 7	2 to 6	1 to 6	2 to 3	1 to 3	1 to 2	0 to 3
Summer	2 to 6	1 to 5	2 to 3	1 to 2	0 to 2	-1 to 1	-2 to 1
Autumn	2 to 10	2 to 5	2 to 3	0 to 3	1 to 3	0 to 2	0 to 2
	30-percentile chart						
Season	.02	.10	.25	.50	.75	.90	.98
Winter	2 to 10	2 to 10	0 to 7	0 to 7	0 to 6	0 to 6	0 to 6C°
Spring	1 to 10	0 to 7	1 to 6	1 to 3	1 to 3	0 to 3	0 to 3
Summer	2 to 7	1 to 6	1 to 3	1 to 3	1 to 2	1 to 2	0 to 2
Autumn	3 to 8	2 to 5	2 to 4	2 to 4	1 to 3	1 to 2	0

Acknowledgments

Iver Lund who has made considerable use of the Third Weather Wing synoptic upper-air data, was the first to urge its use in this project. The AFCRL Computer Laboratory's contractor, Analysis and Computer Systems, Inc., Burlington, Massachusetts, devised the programs. Mr. Don Armstrong prepared the data for action by his associate Mrs. Jean Chin whose programs produced the maps and the printouts of 3-, 6-, and 12-station minima.

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Plates and Graphs

The plates are in groups of seven, to cover the 2, 10, 25, 50, 75, 90, 98 percentiles of temperature (^{o}C) at a given level and season. One graph accompanies each plate to give the probability that the temperature on the map will be equalled or exceeded on a selected route of given length and mid-latitude.

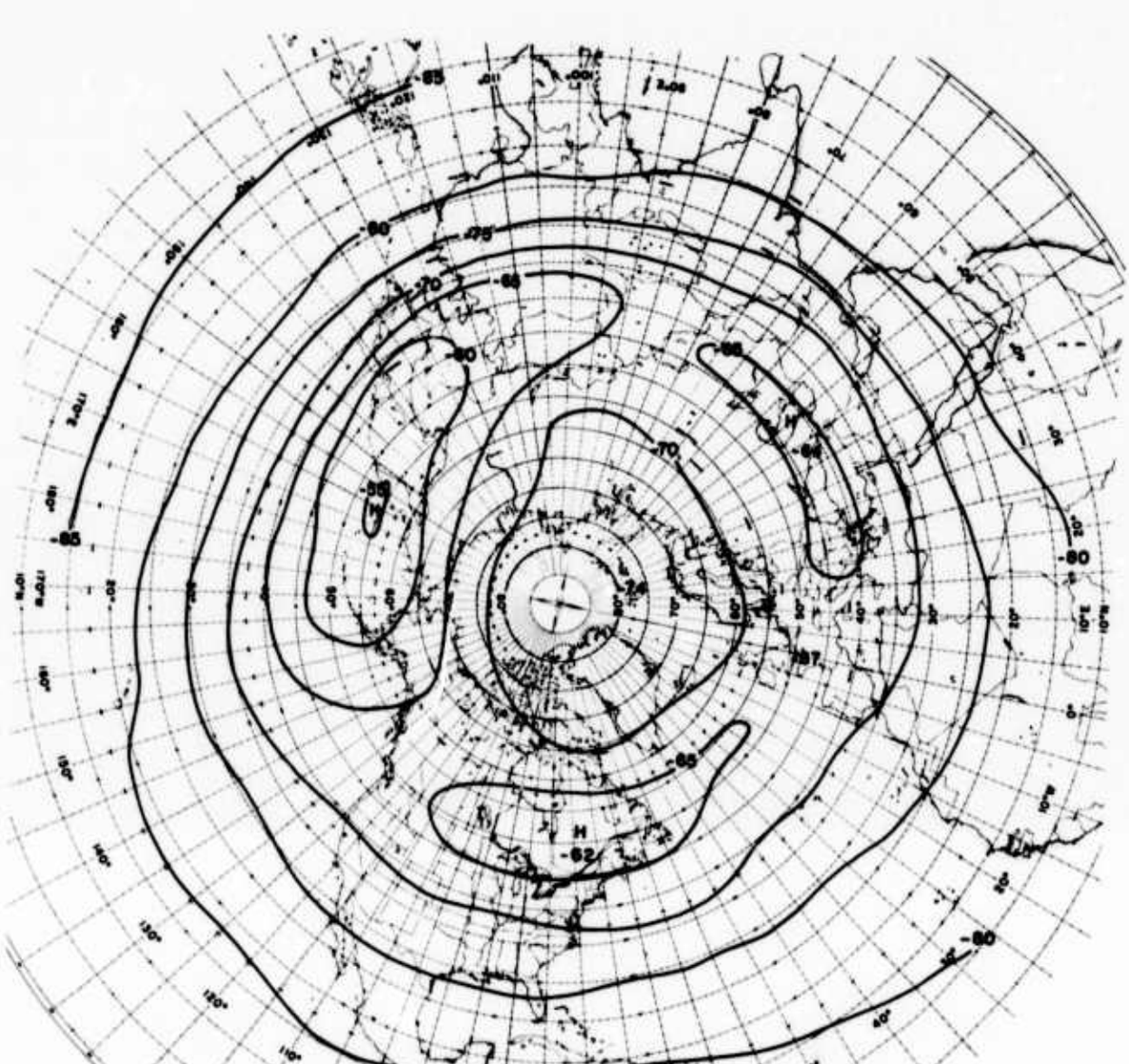
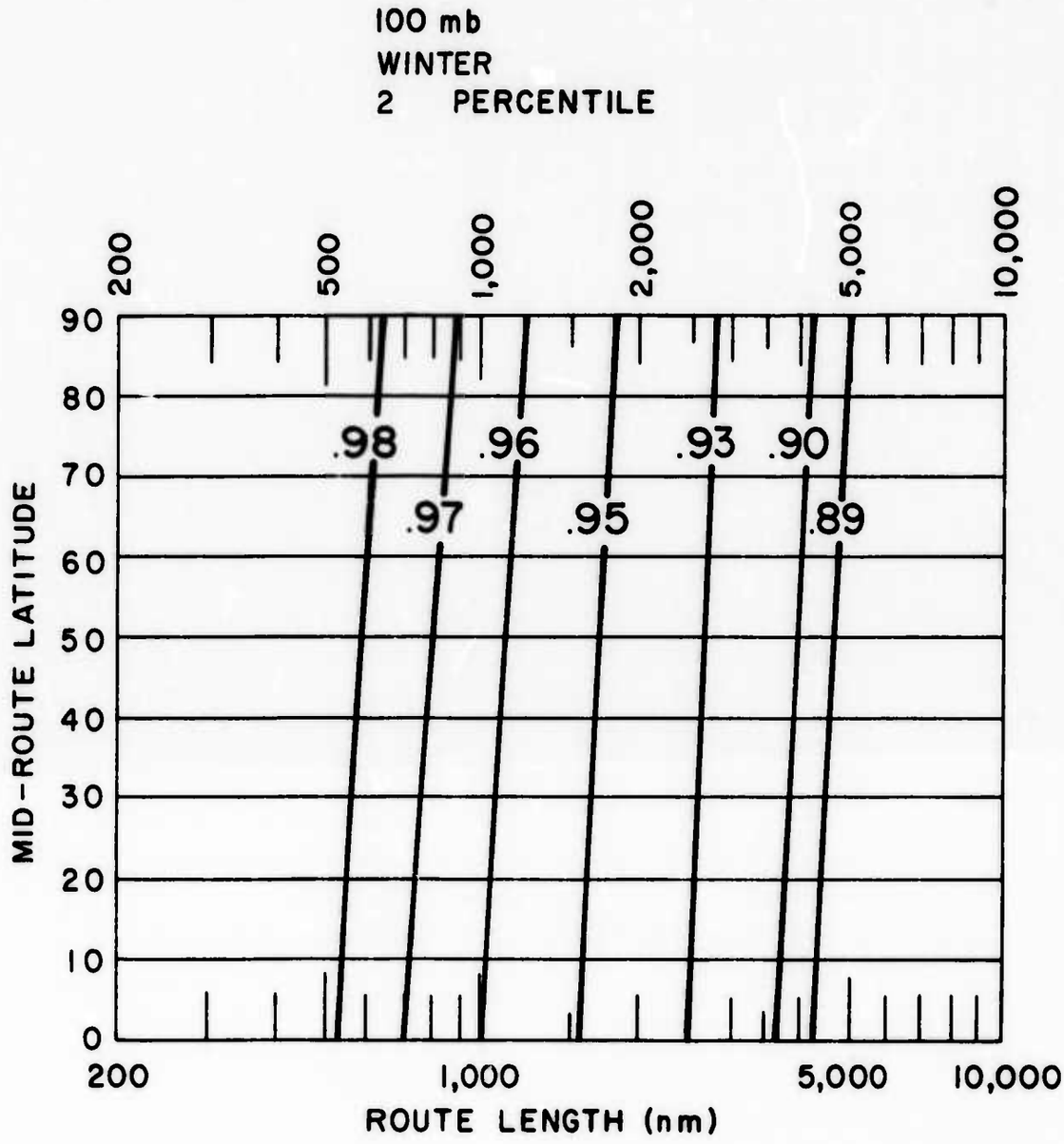


Plate 1. Temperature at 100 mb, in December, January, and February, 2 Percentile



Graph 1. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

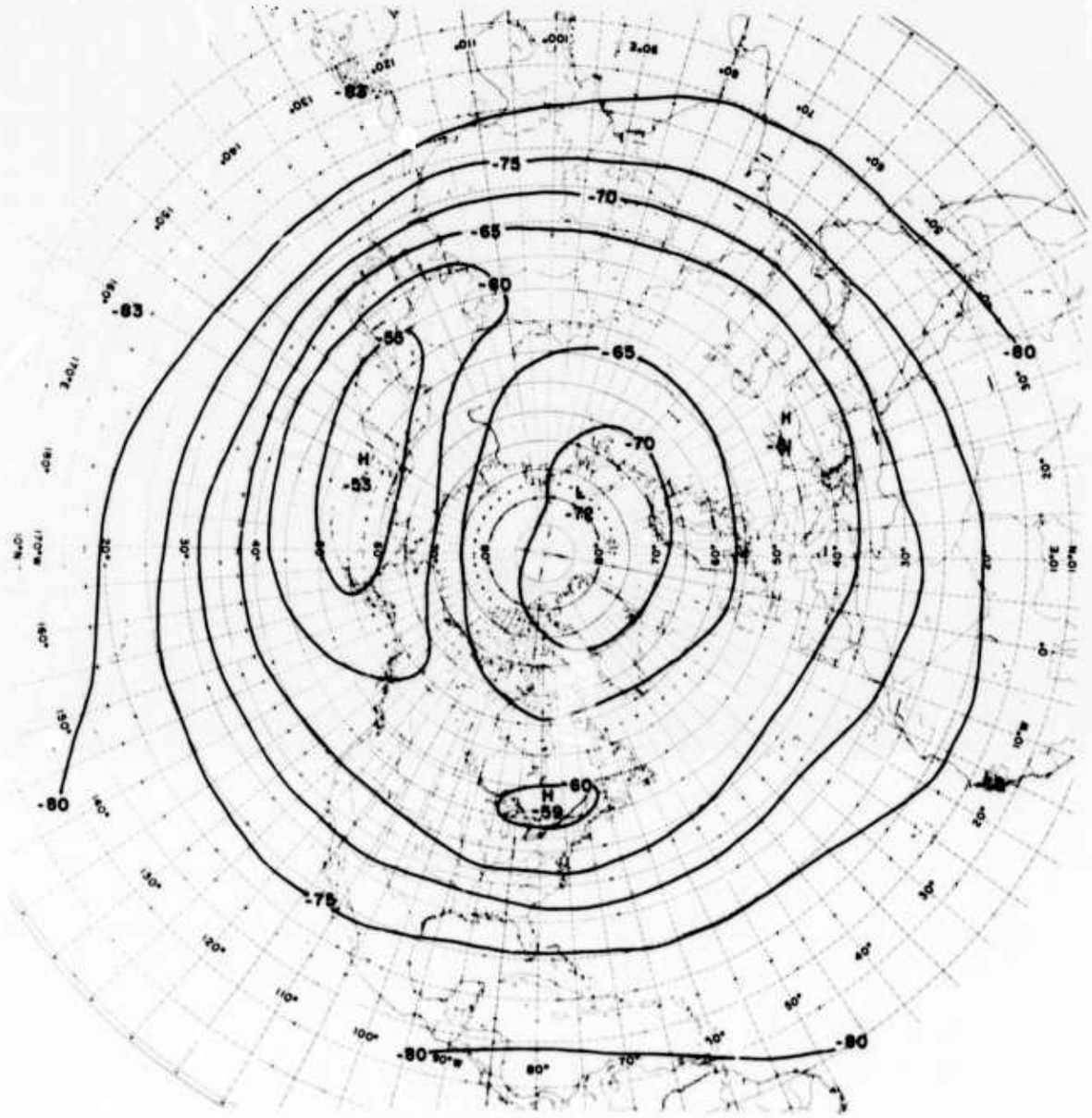
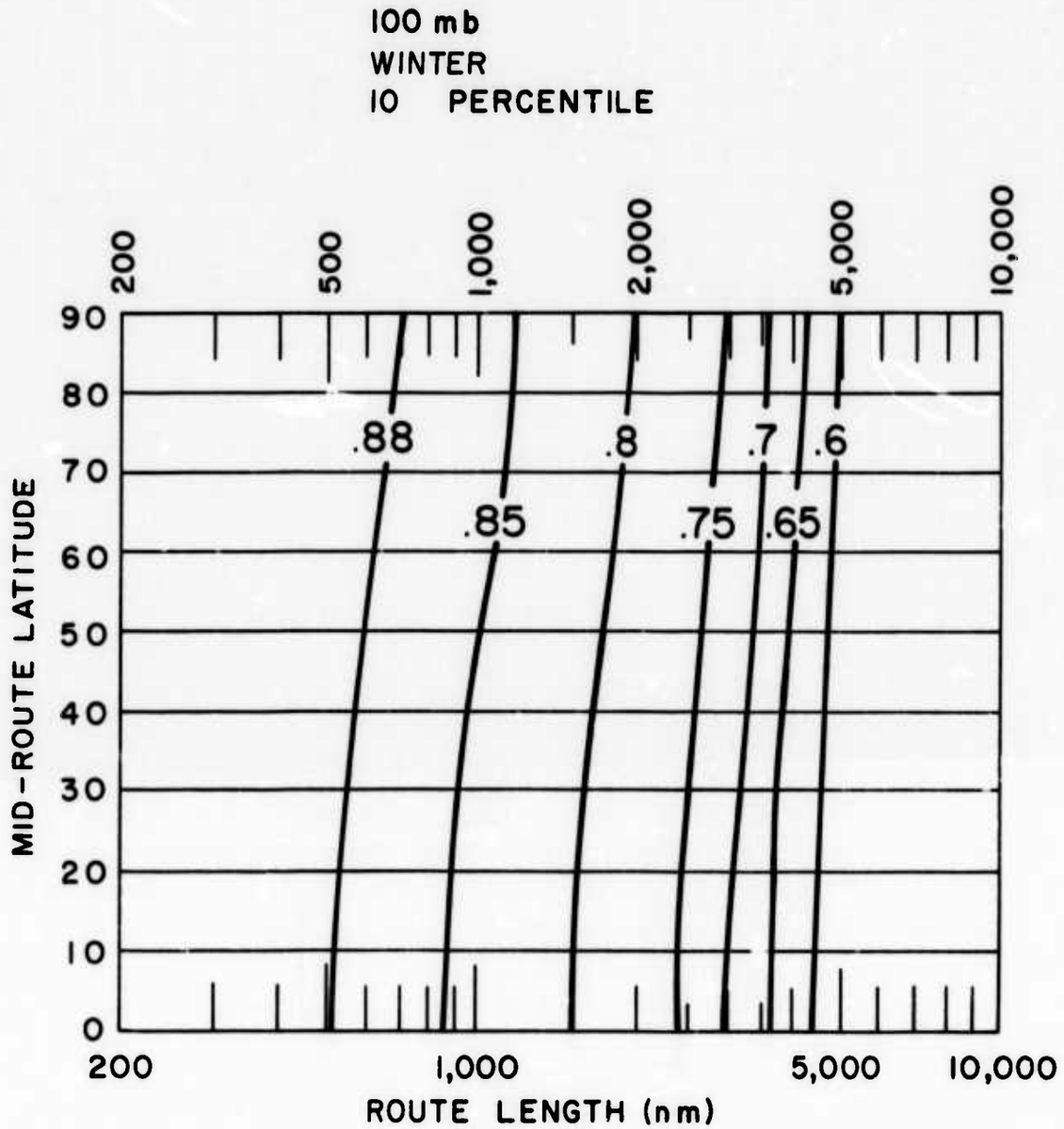


Plate 2. Temperature at 100 mb, in December, January, and February, 10 Percentile



Graph 2. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

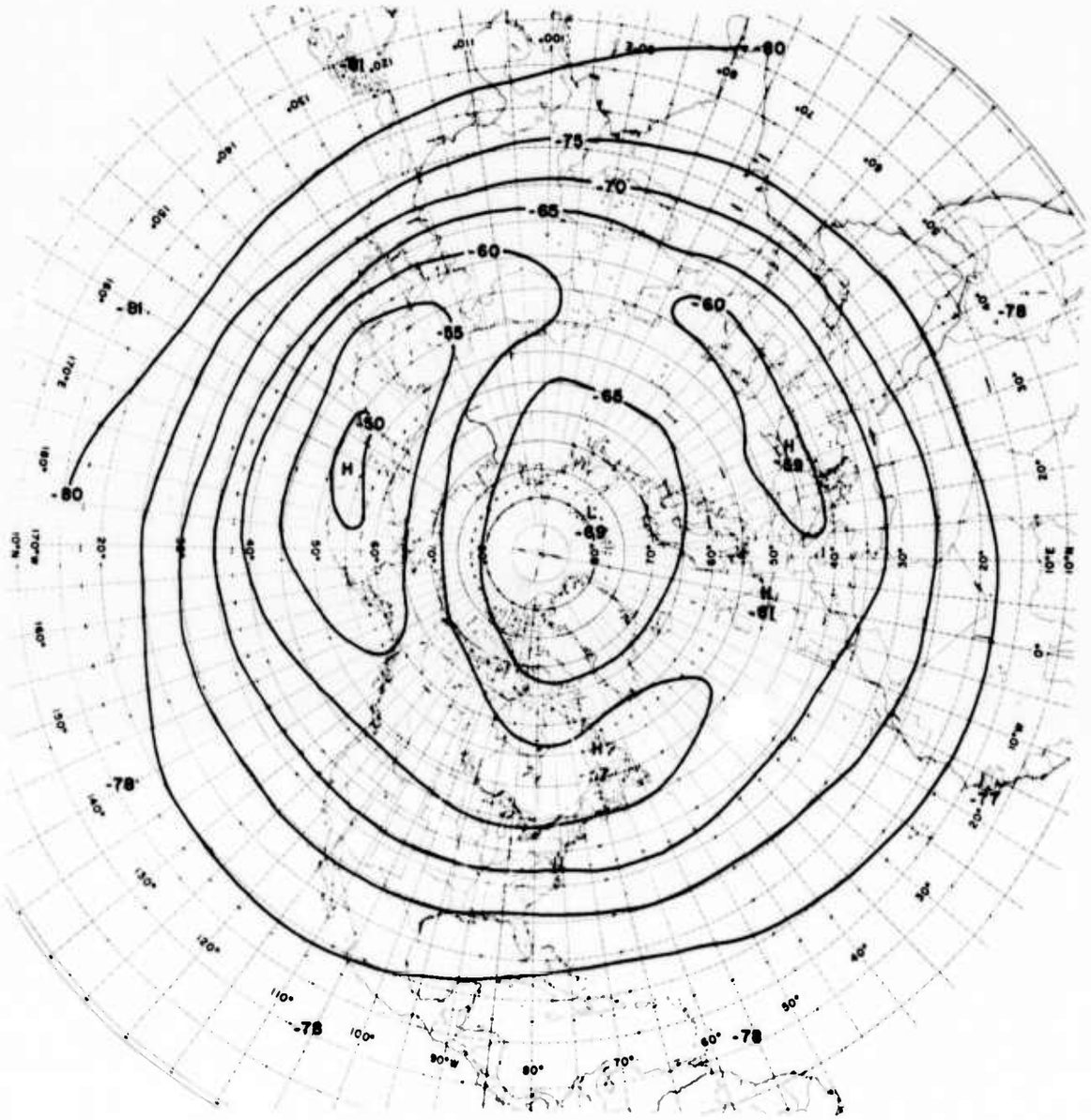
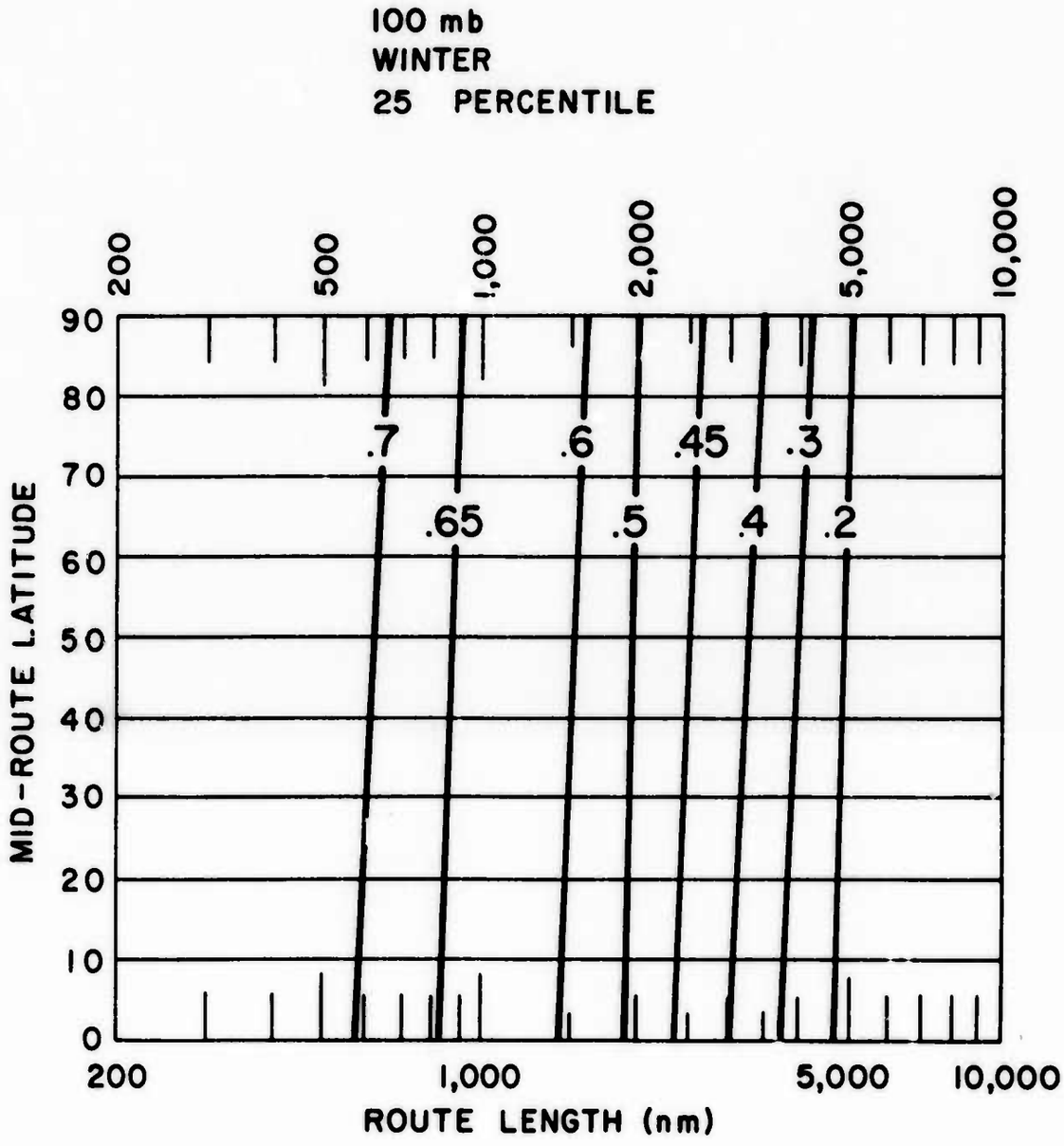


Plate 3. Temperature at 100 mb, in December, January, and February, 25 Percentile



Graph 3. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

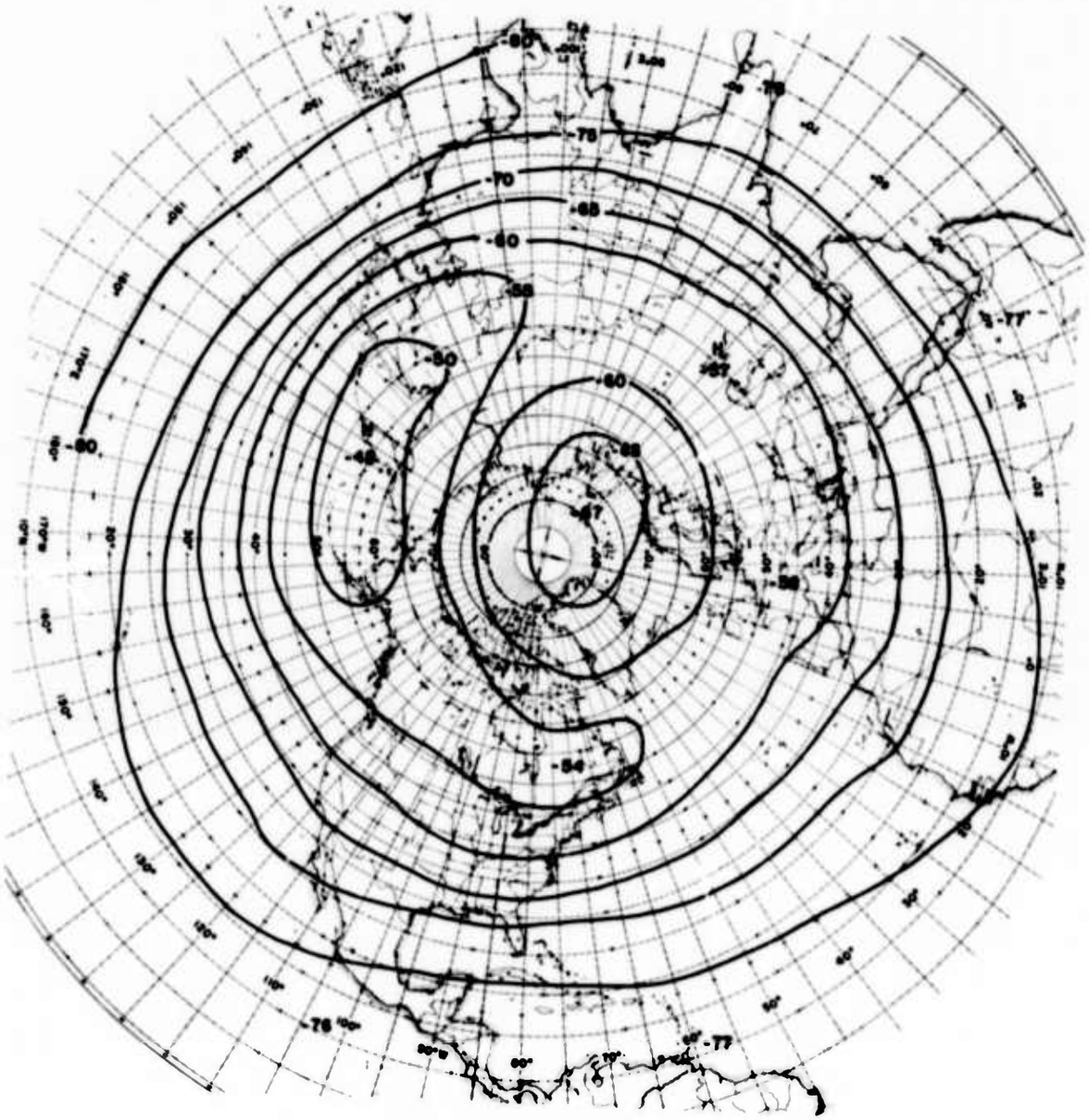
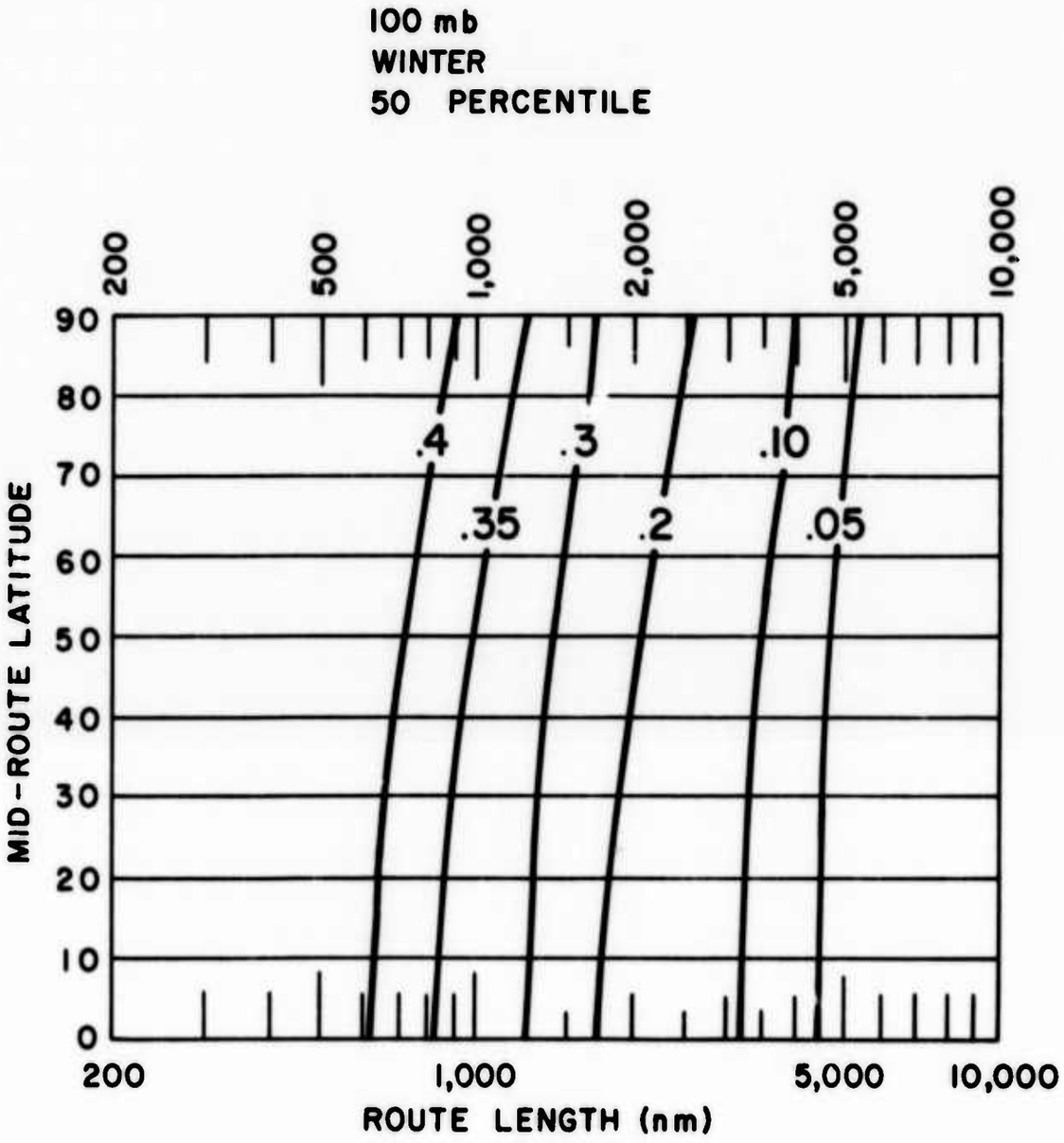


Plate 4. Temperature at 100 mb, in December, January, and February, 50 Percentile



Graph 4. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

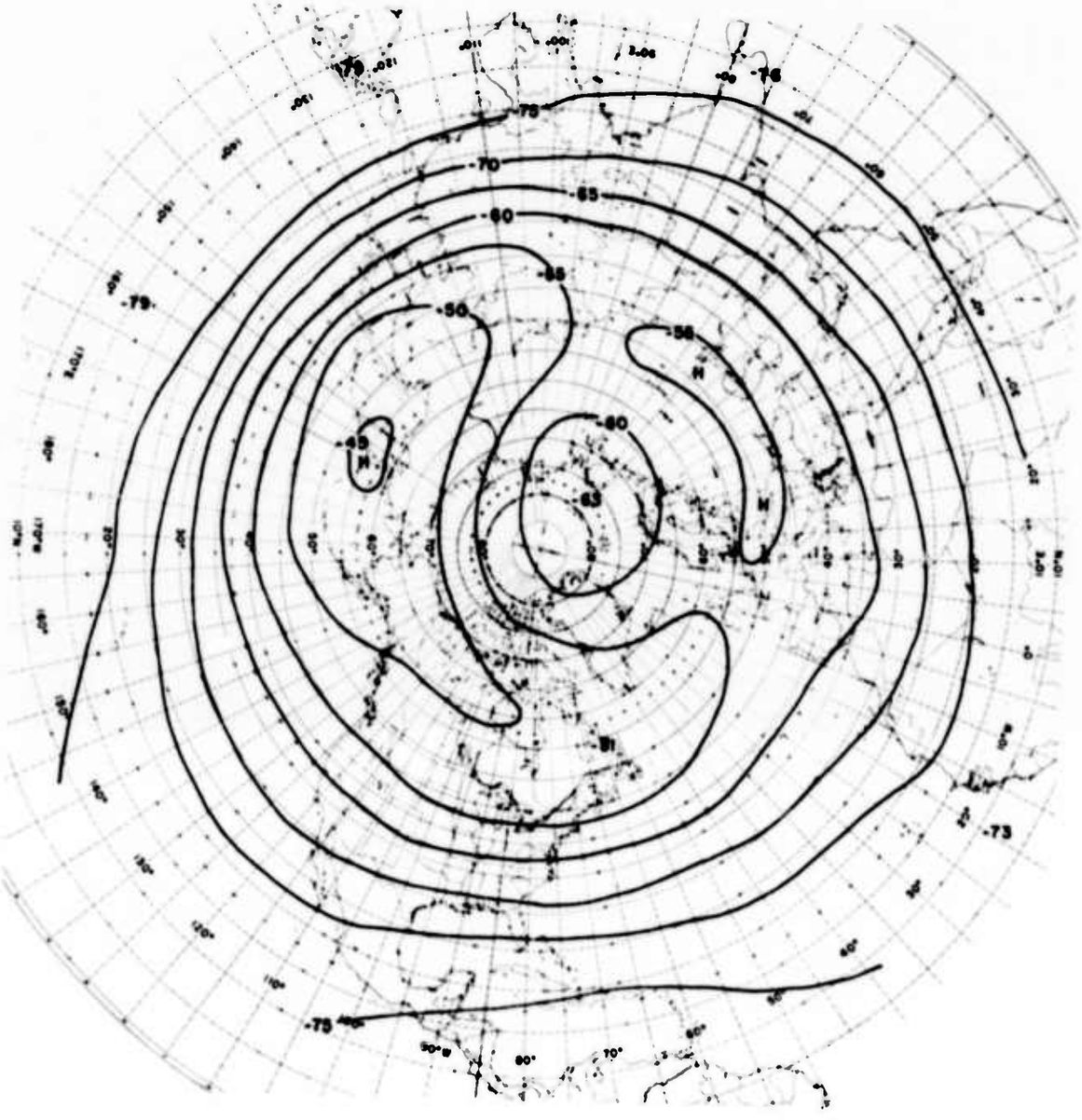
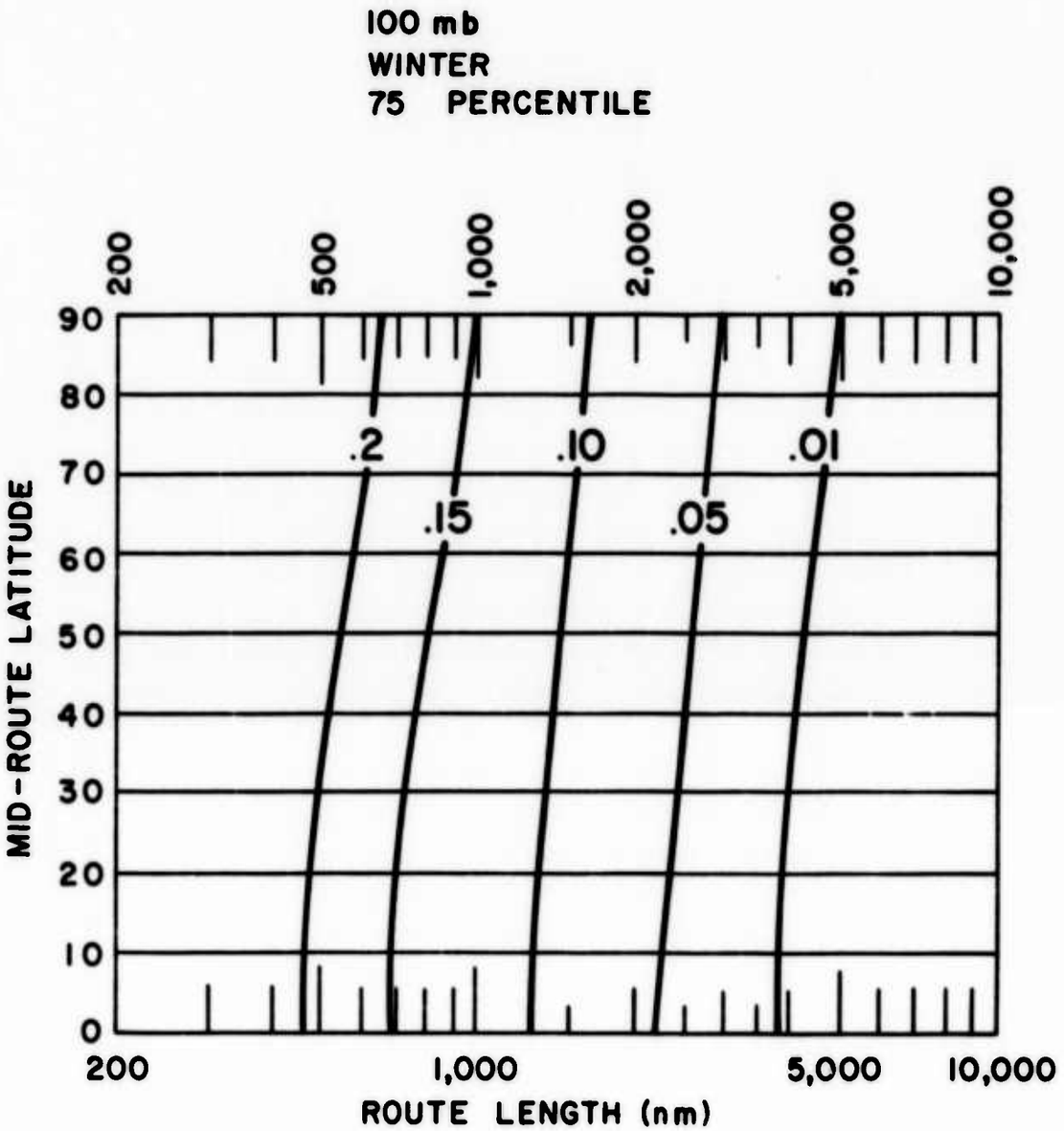


Plate 5. Temperature at 100 mb, in December, January, and February, 75 Percentile



Graph 5. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

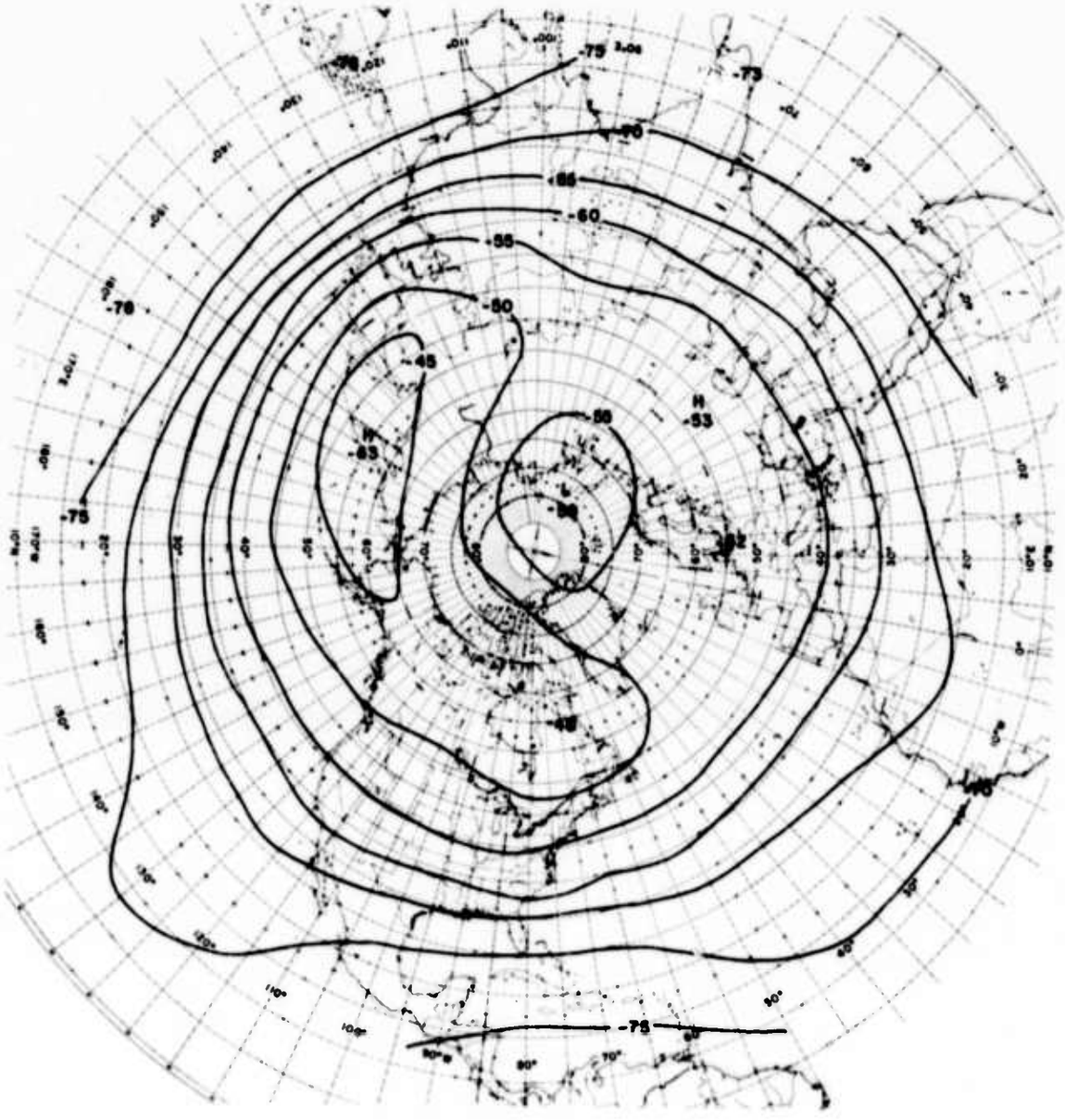
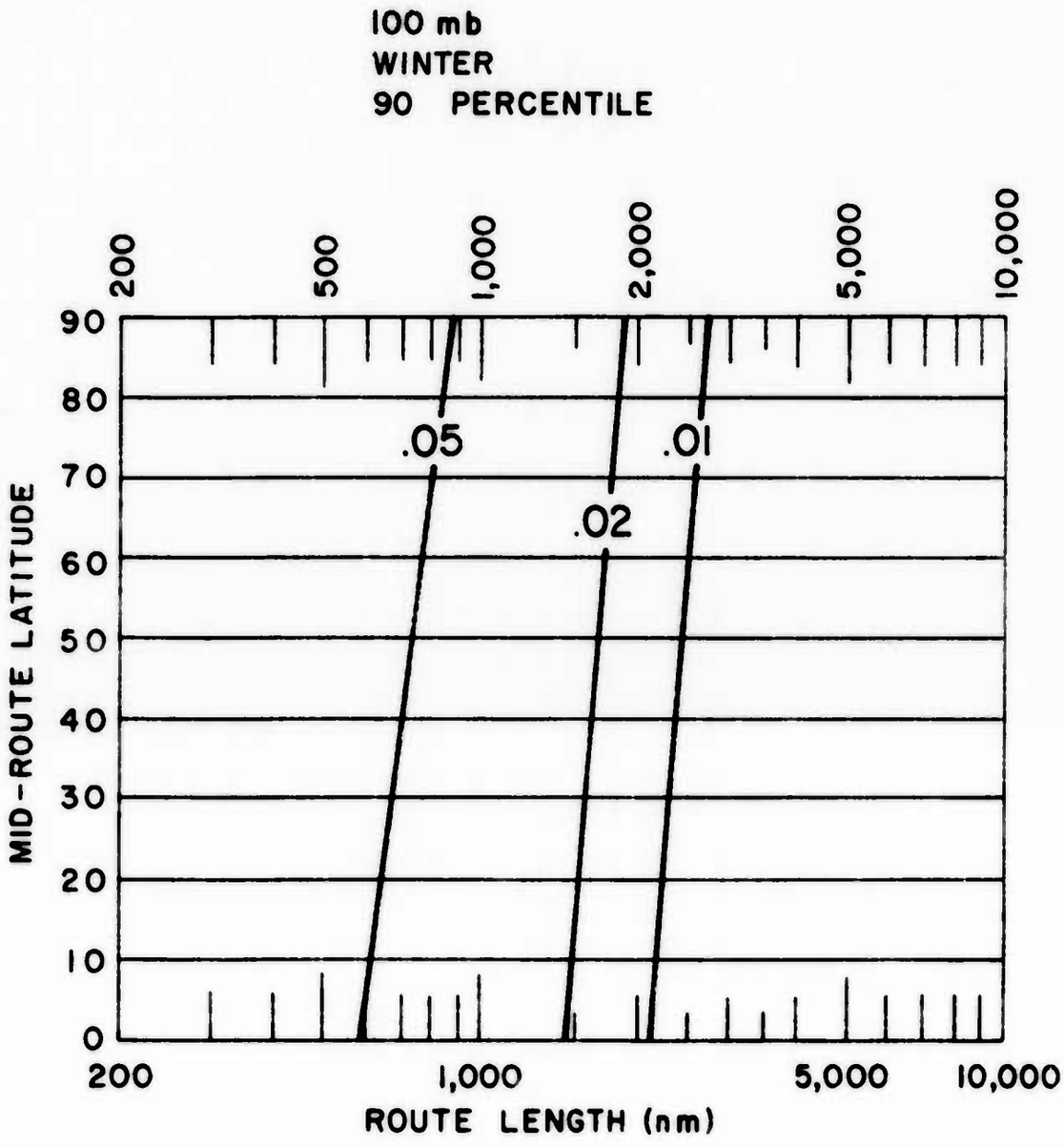


Plate 6. Temperature at 100 mb, in December, January, and February, 90 Percentile



Graph 6. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

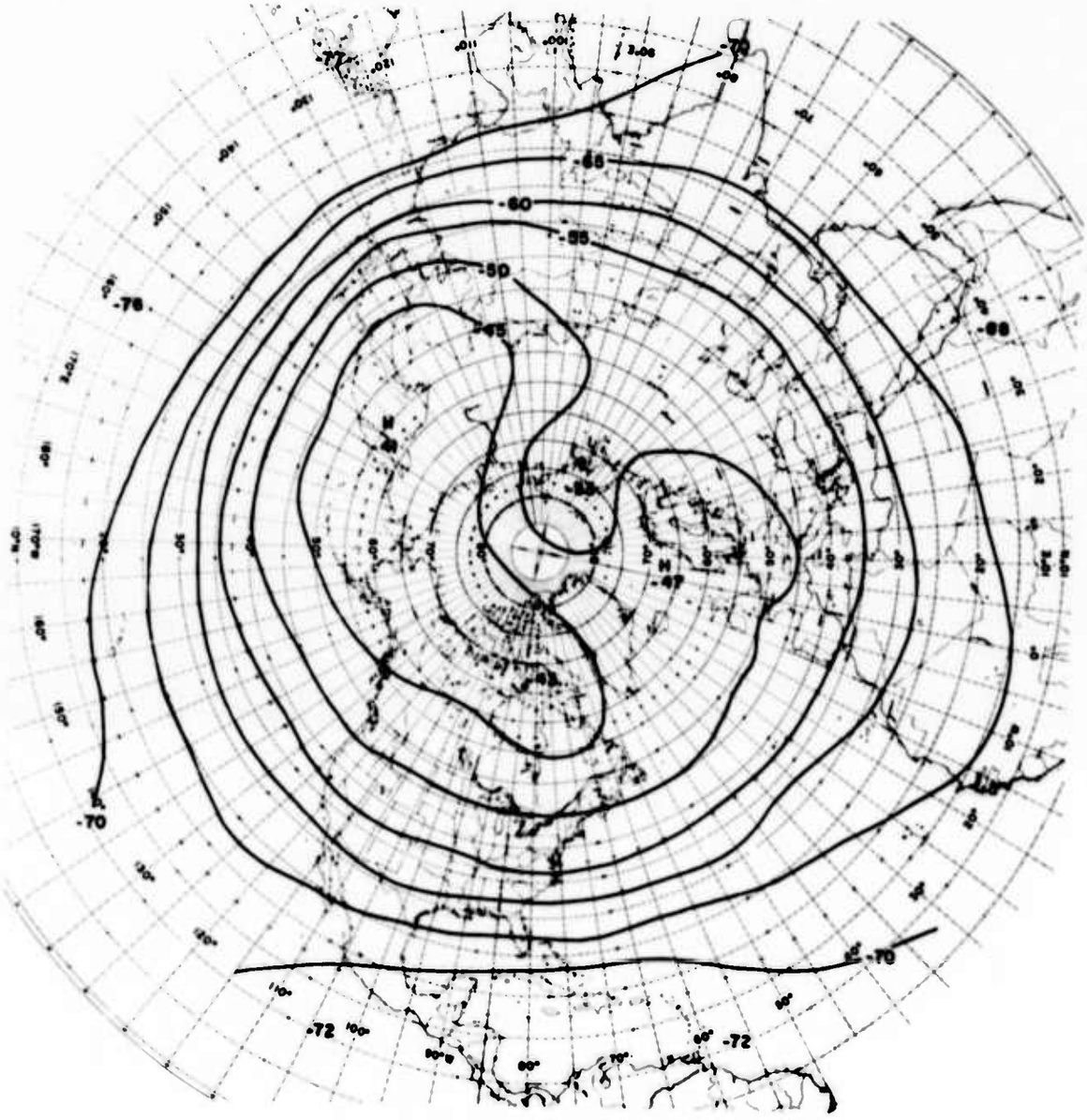
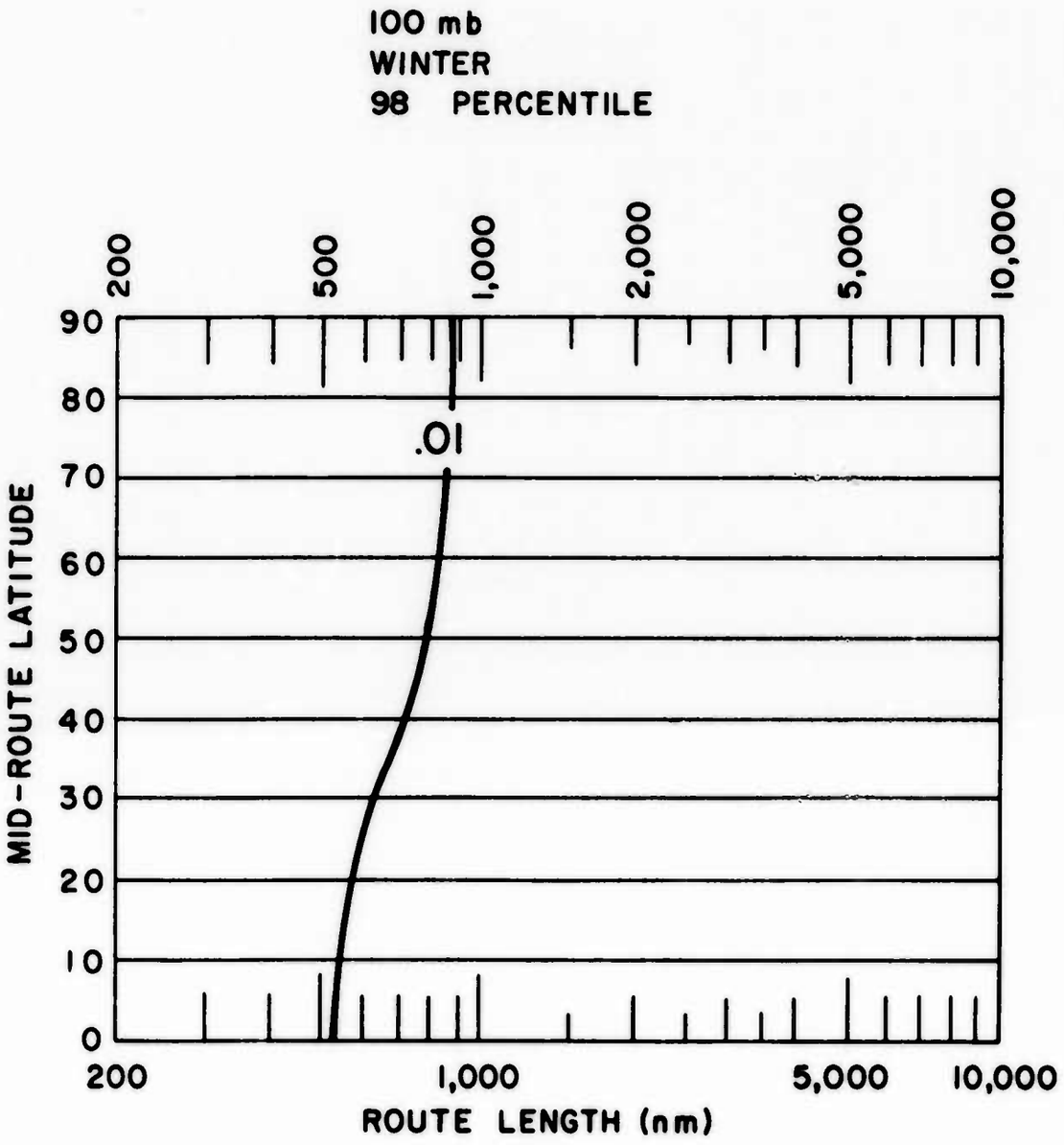


Plate 7. Temperature at 100 mb, in December, January, and February, 98 Percentile



Graph 7. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

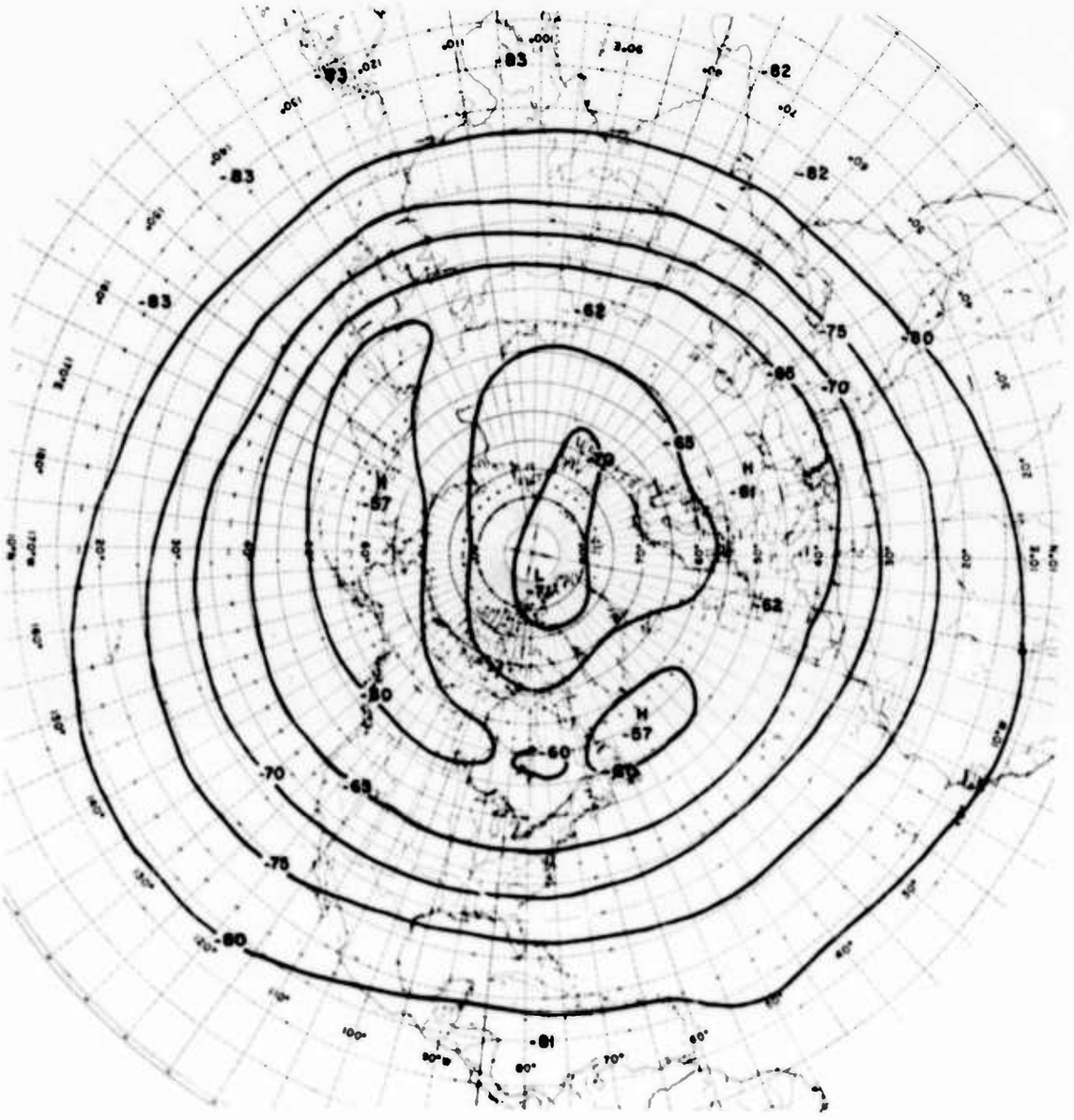
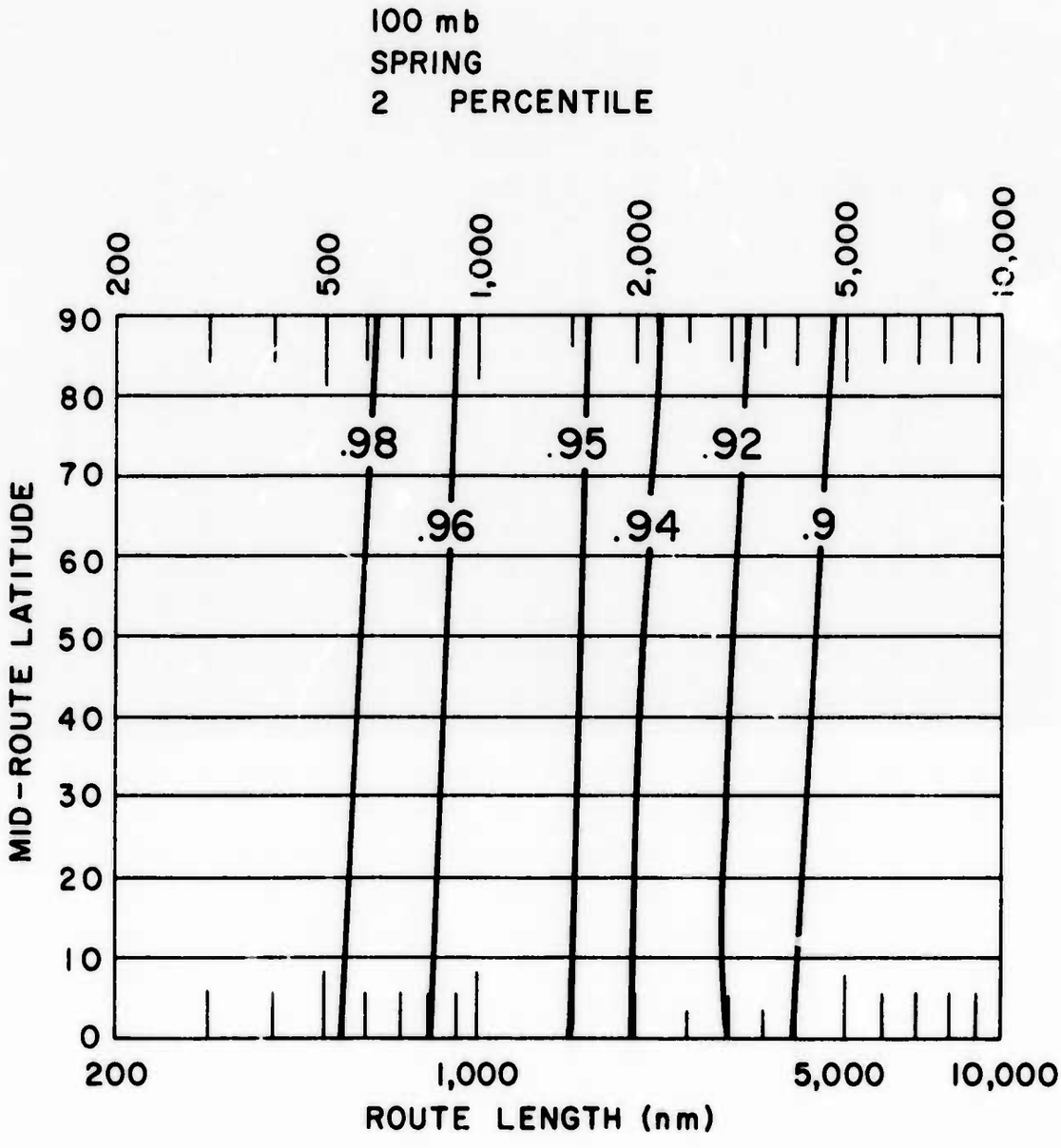


Plate 8. Temperature at 100 mb, in March, April, May, 2 Percentile



Graph 8. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

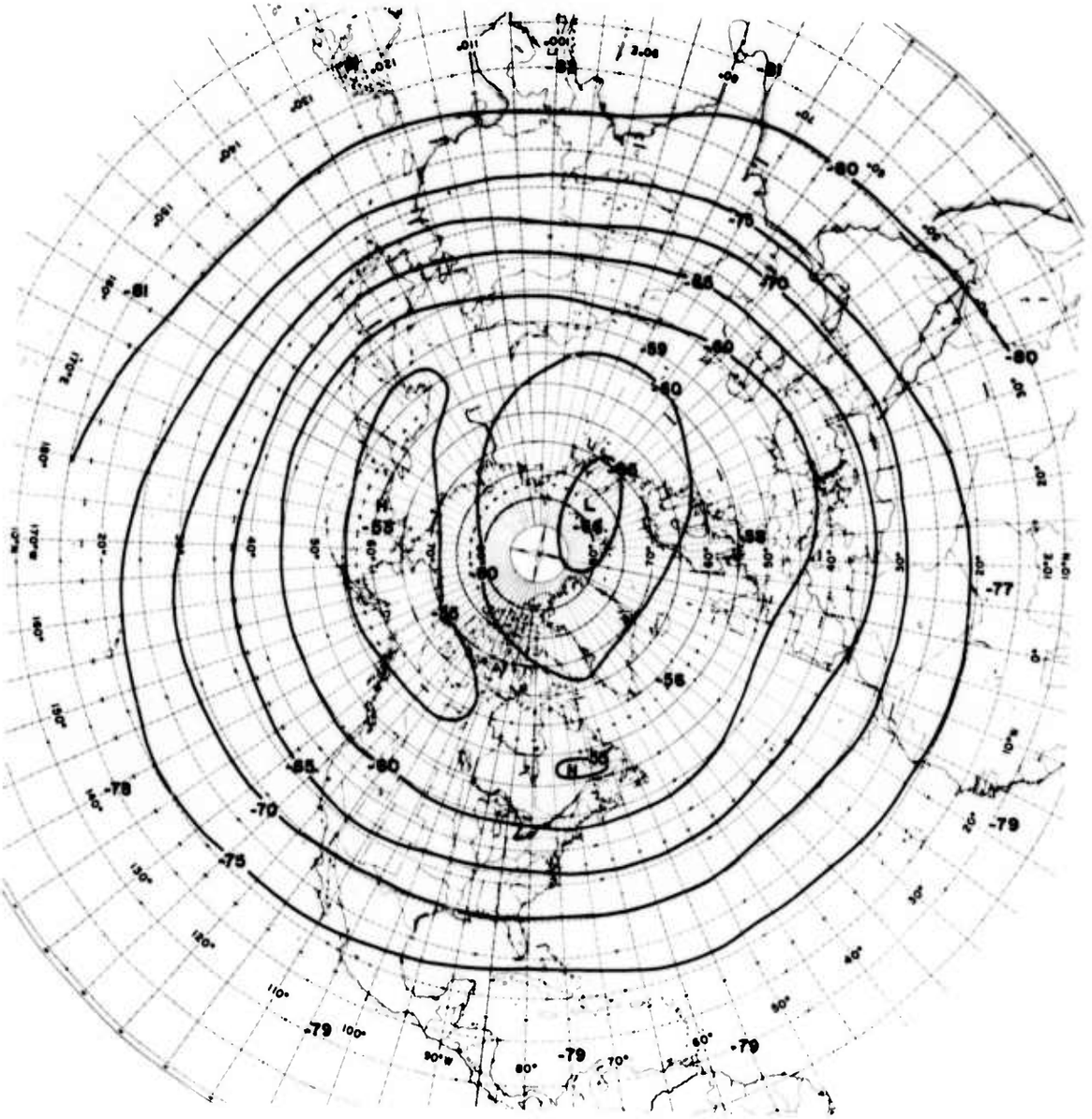
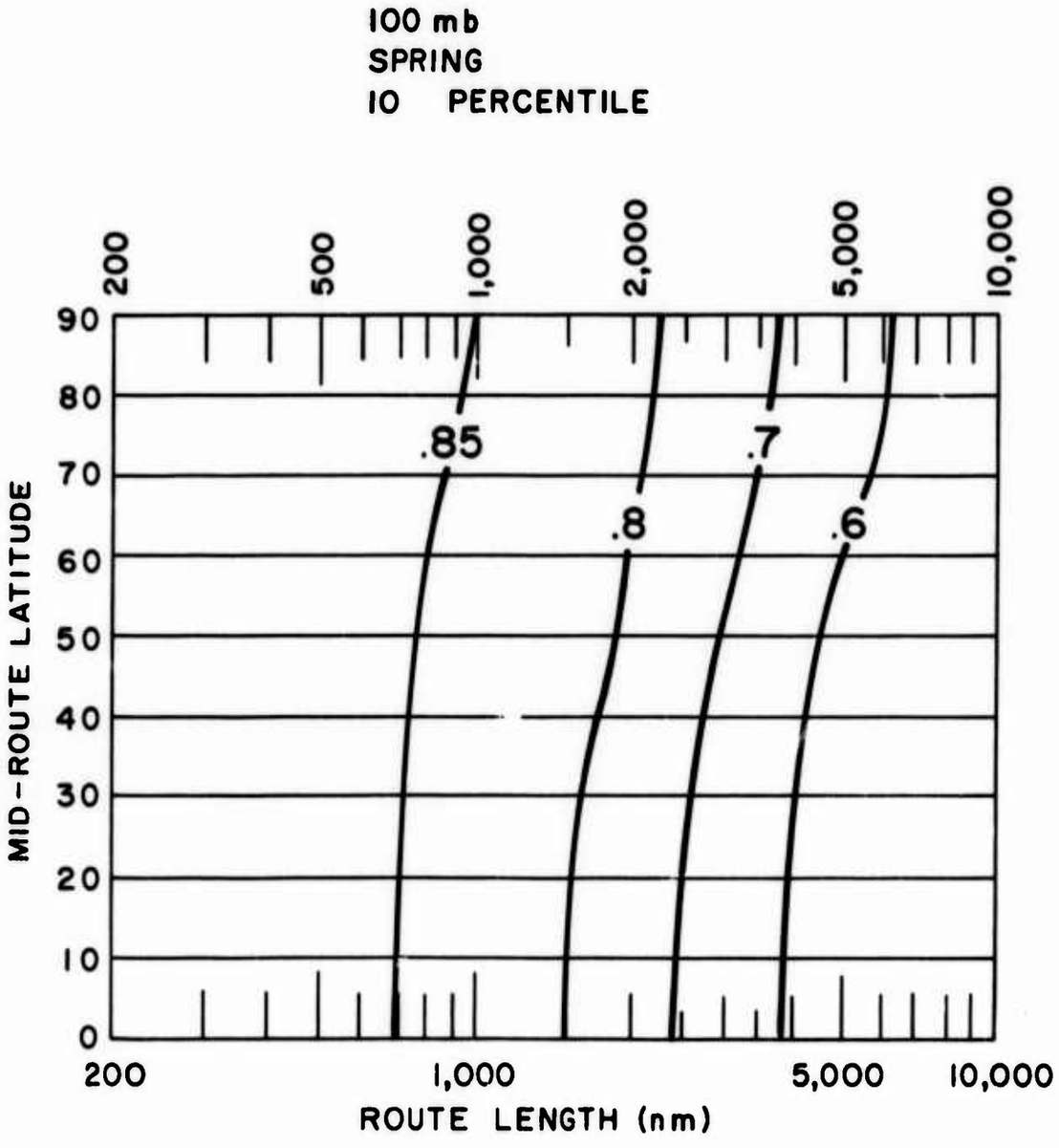


Plate 9. Temperature at 100 mb, in March, April, May, 10 Percentile



Graph 9. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

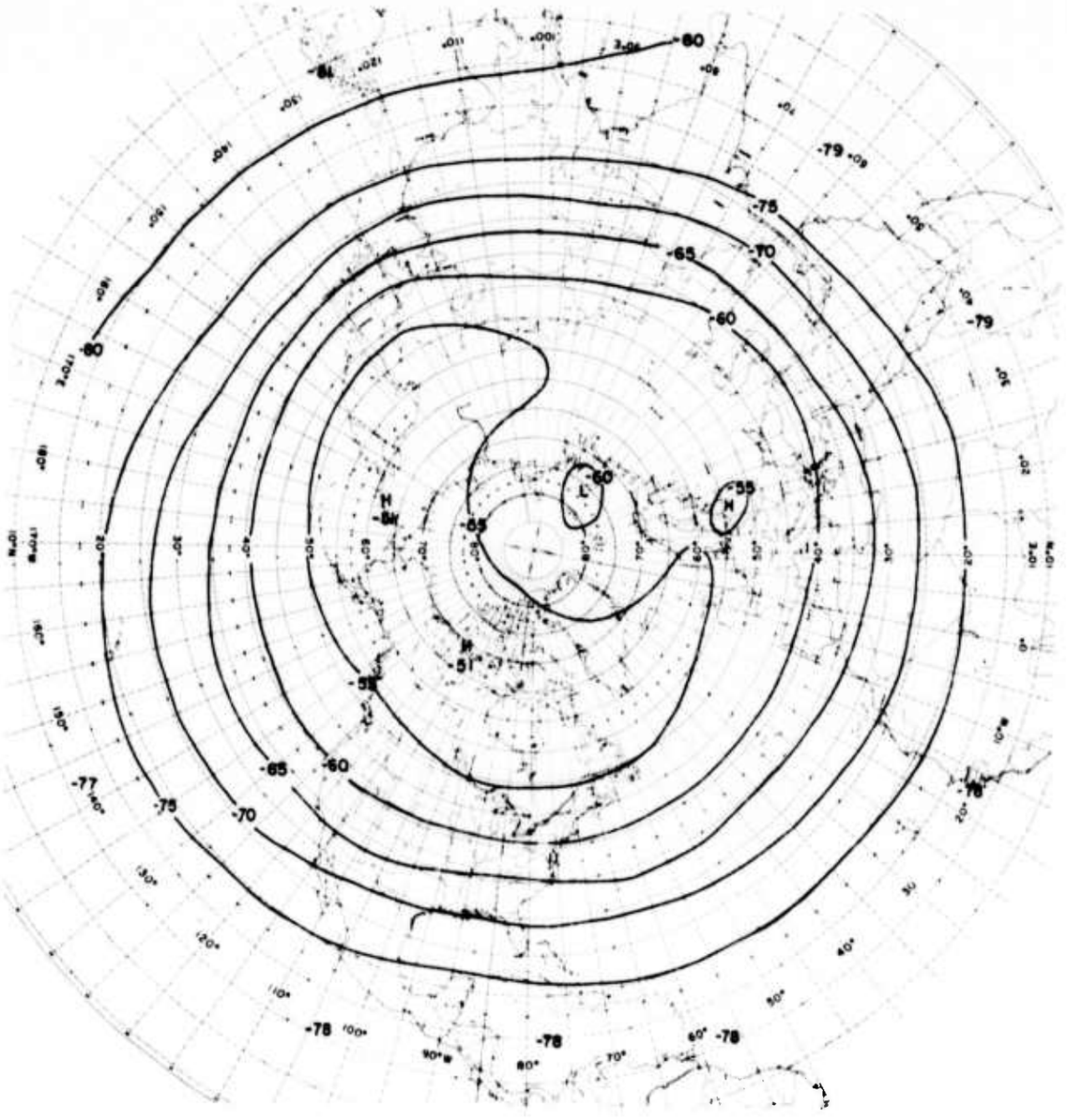
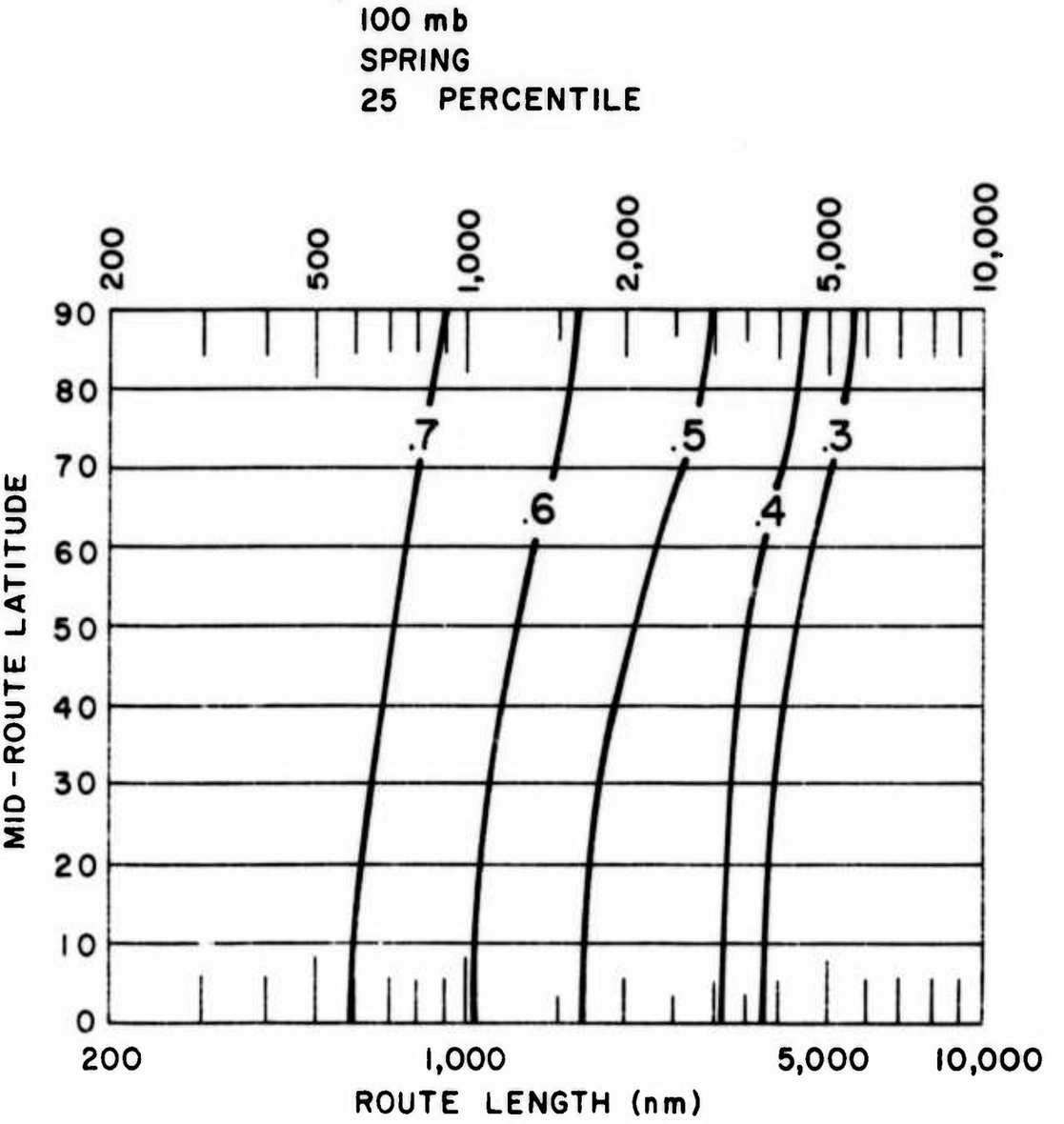


Plate 10. Temperature at 100 mb, in March, April, May, 25 Percentile



Graph 10. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

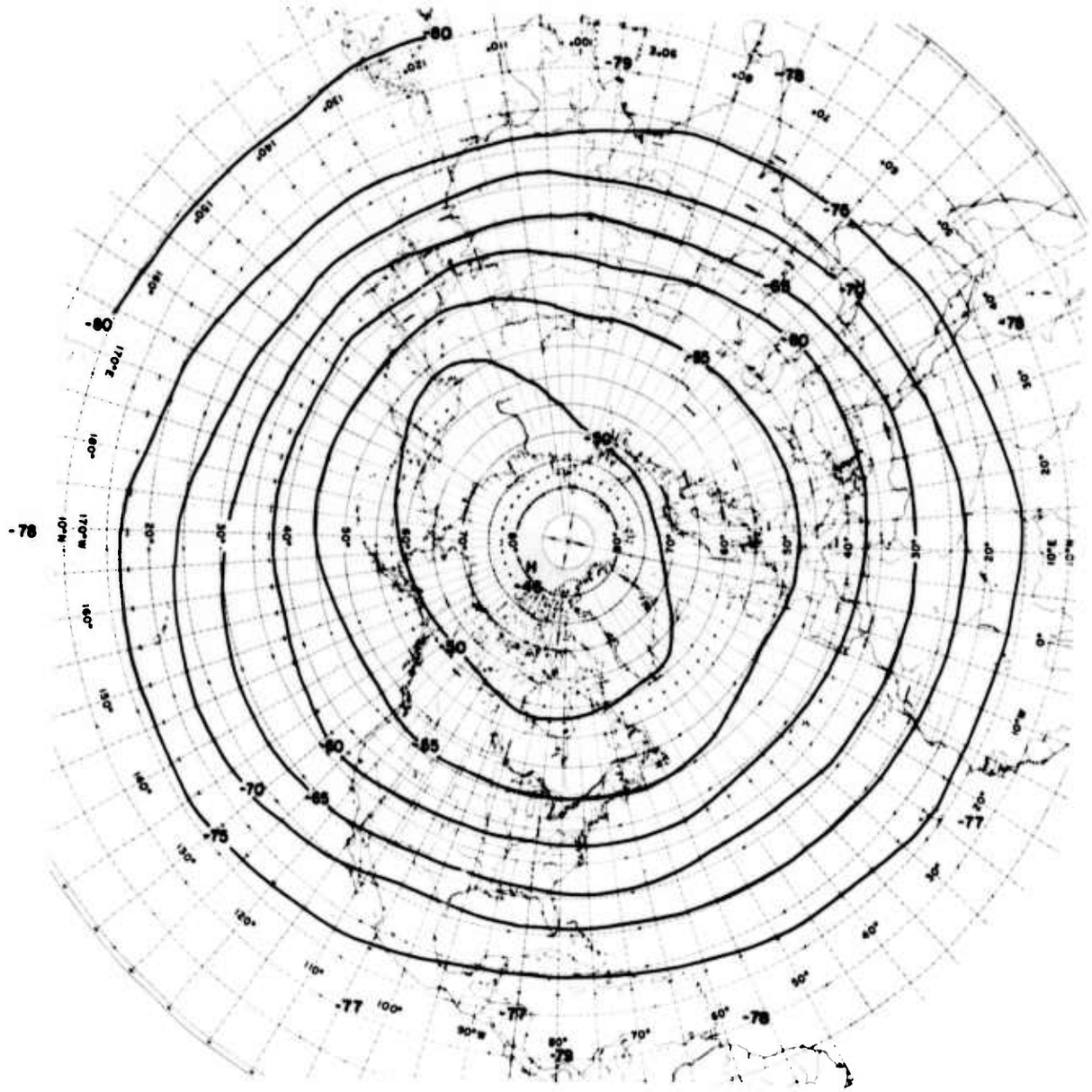
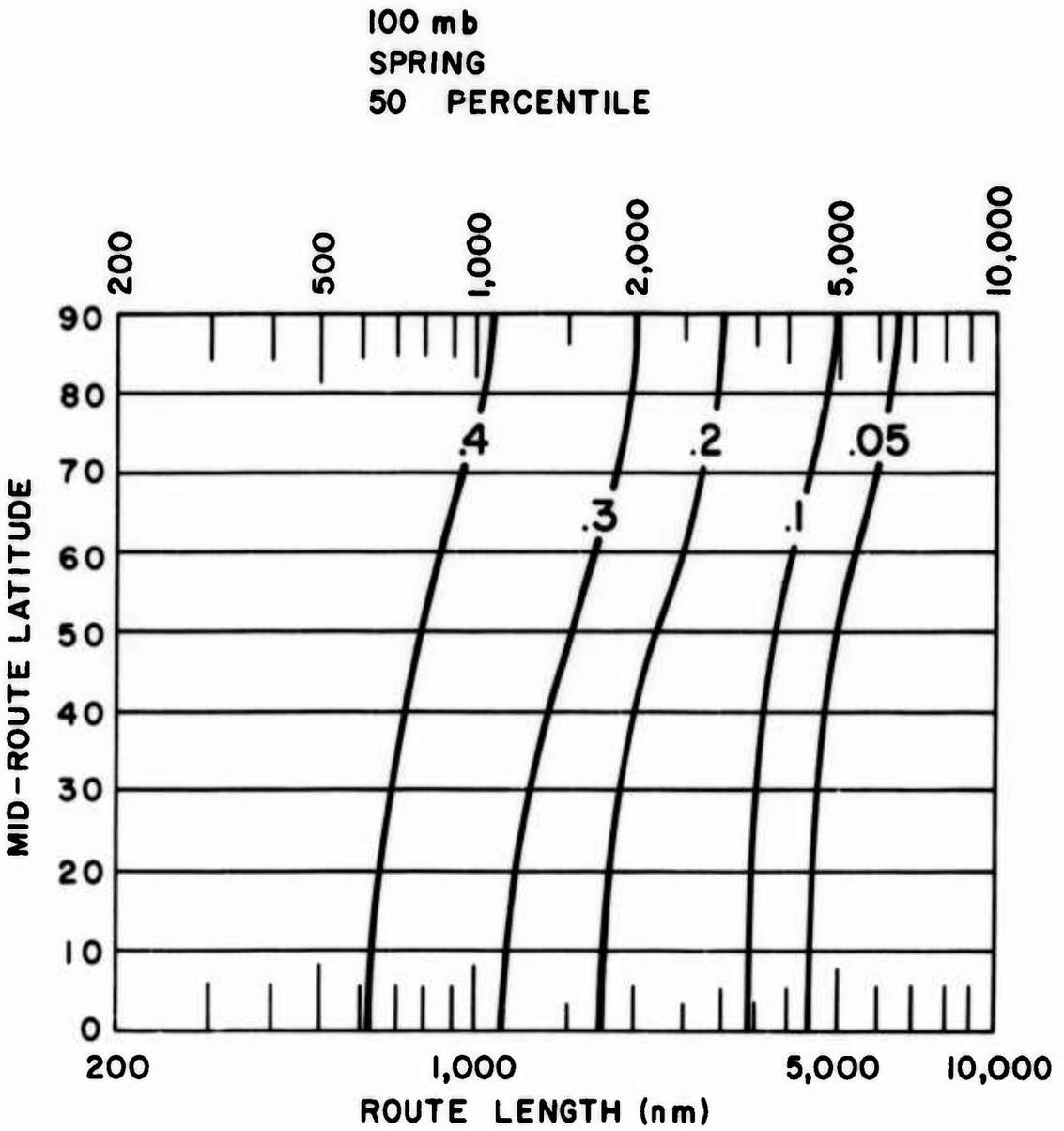


Plate 11. Temperature at 100 mb, in March, April, May, 50 Percentile



Graph 11. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

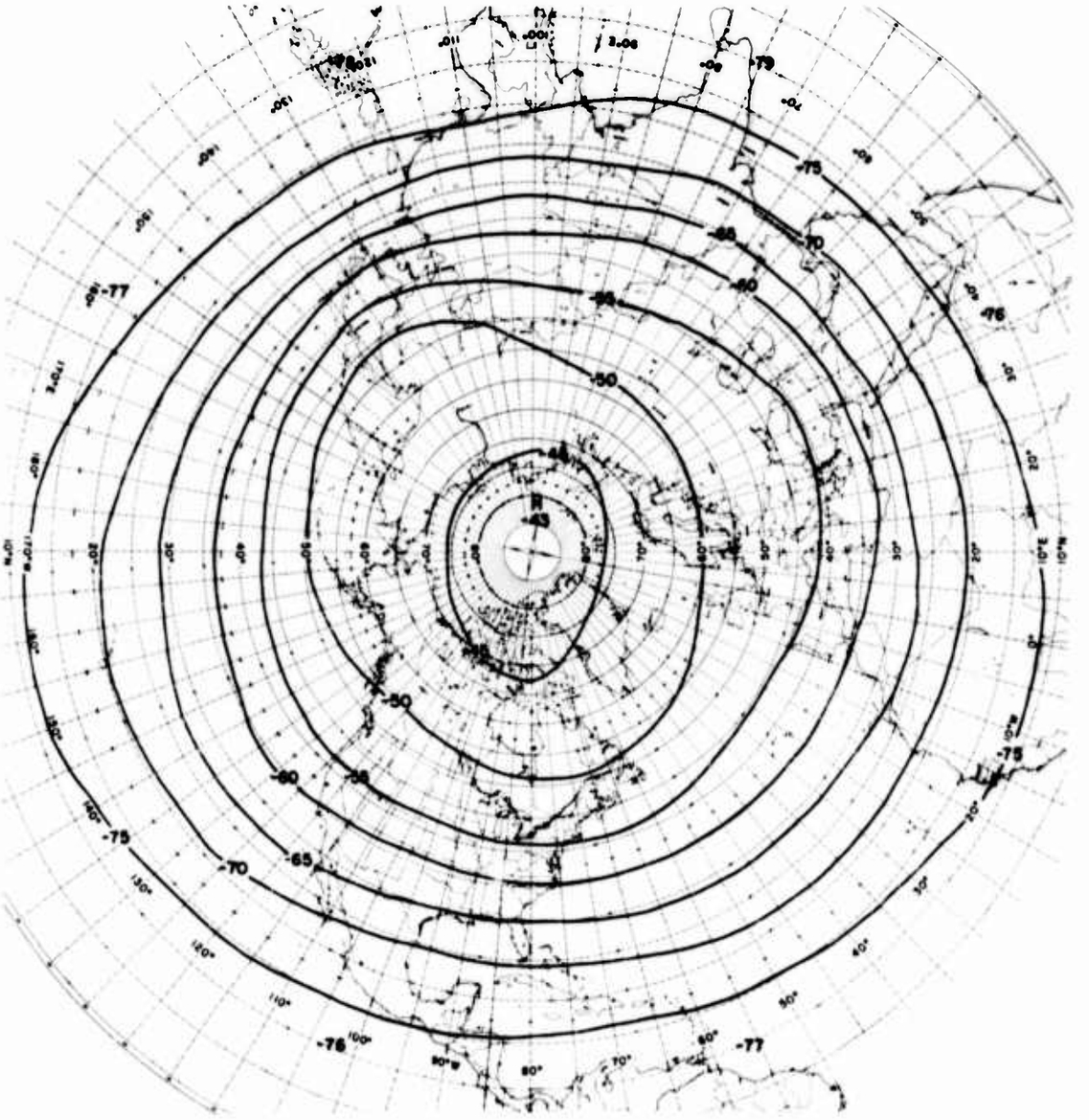
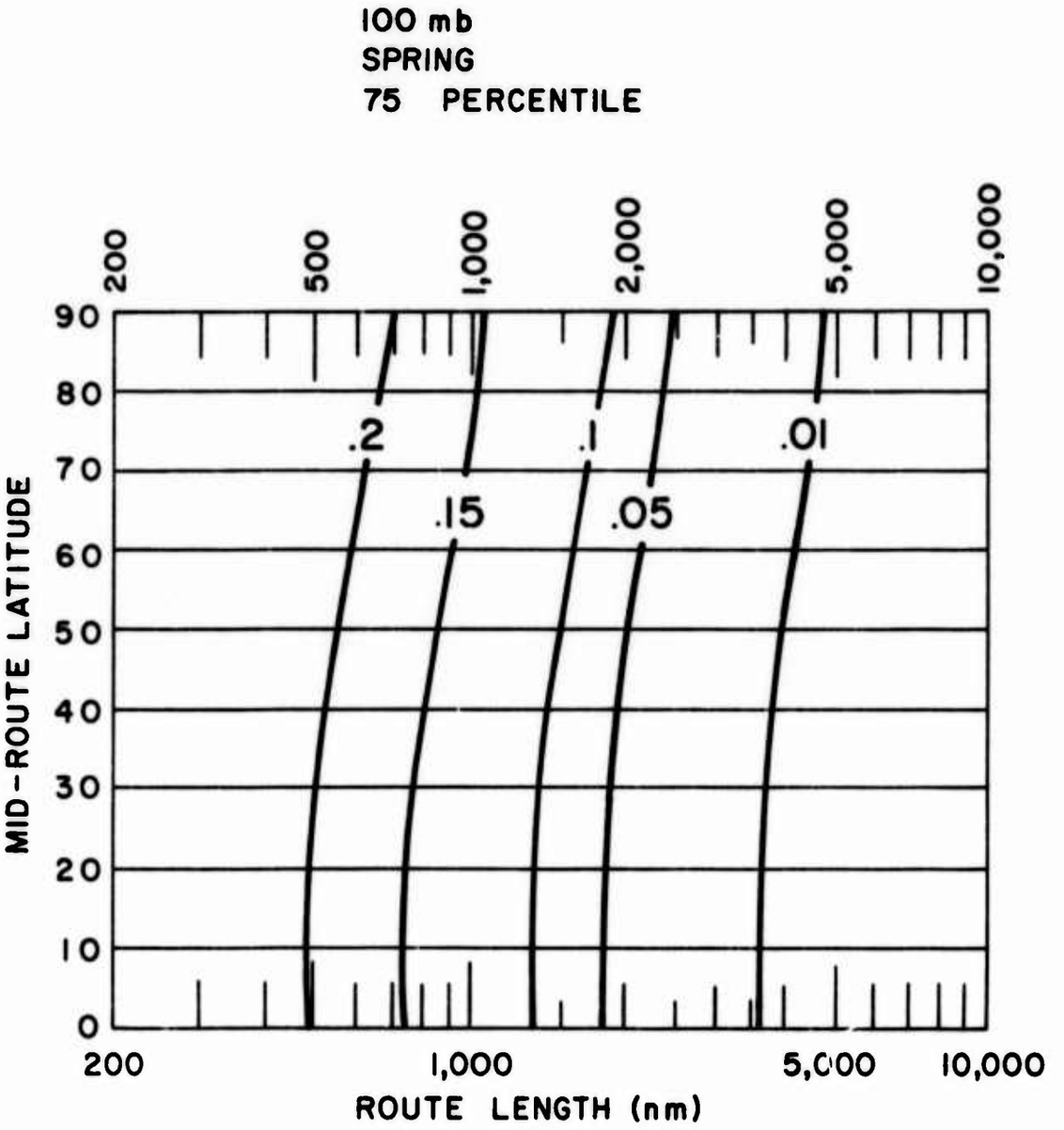


Plate 12. Temperature at 100 mb, in March, April, May, 75 Percentile



Graph 12. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

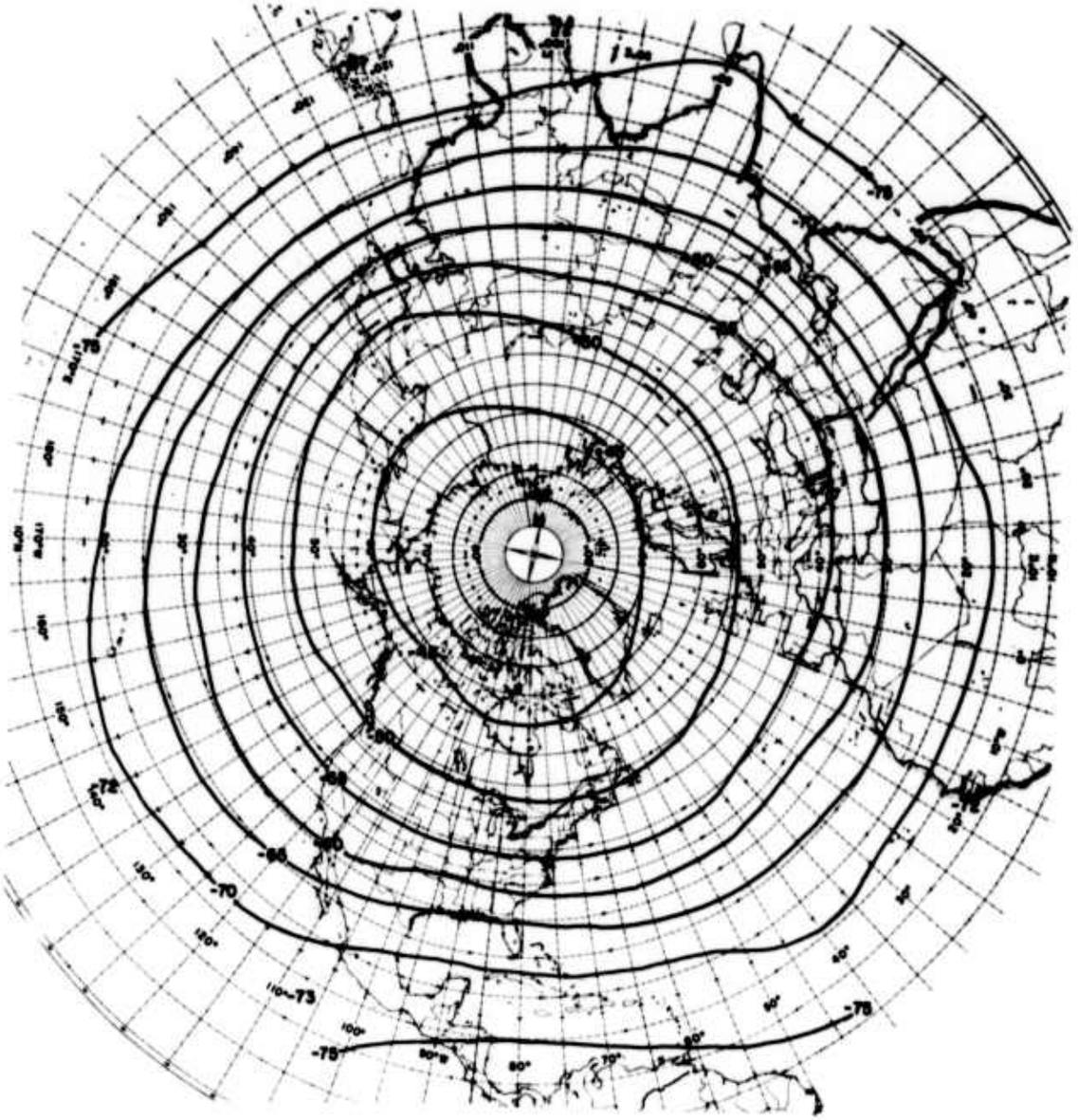
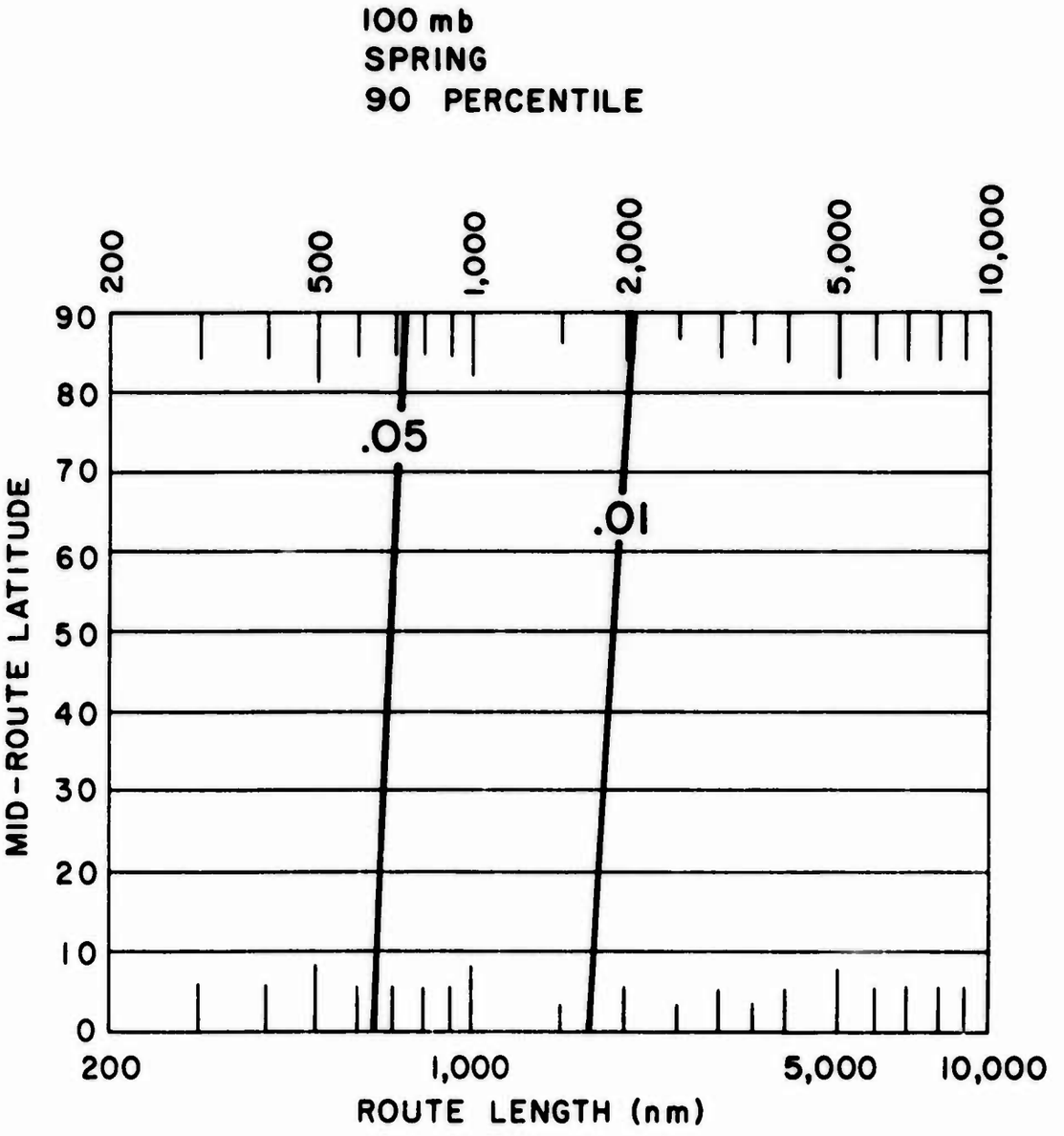


Plate 13. Temperature at 100 mb, in March, April, May, 90 Percentile



Graph 13. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

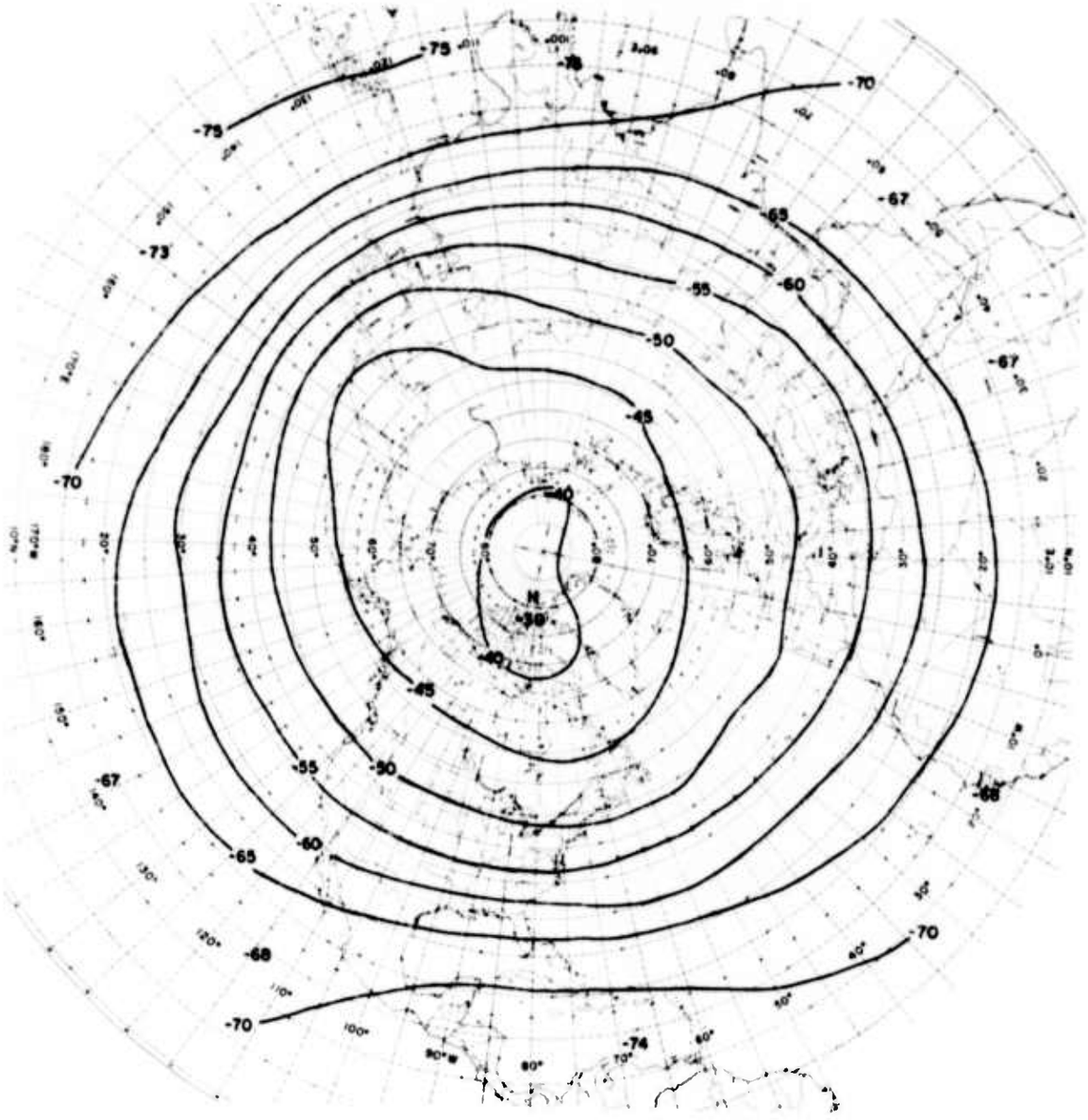
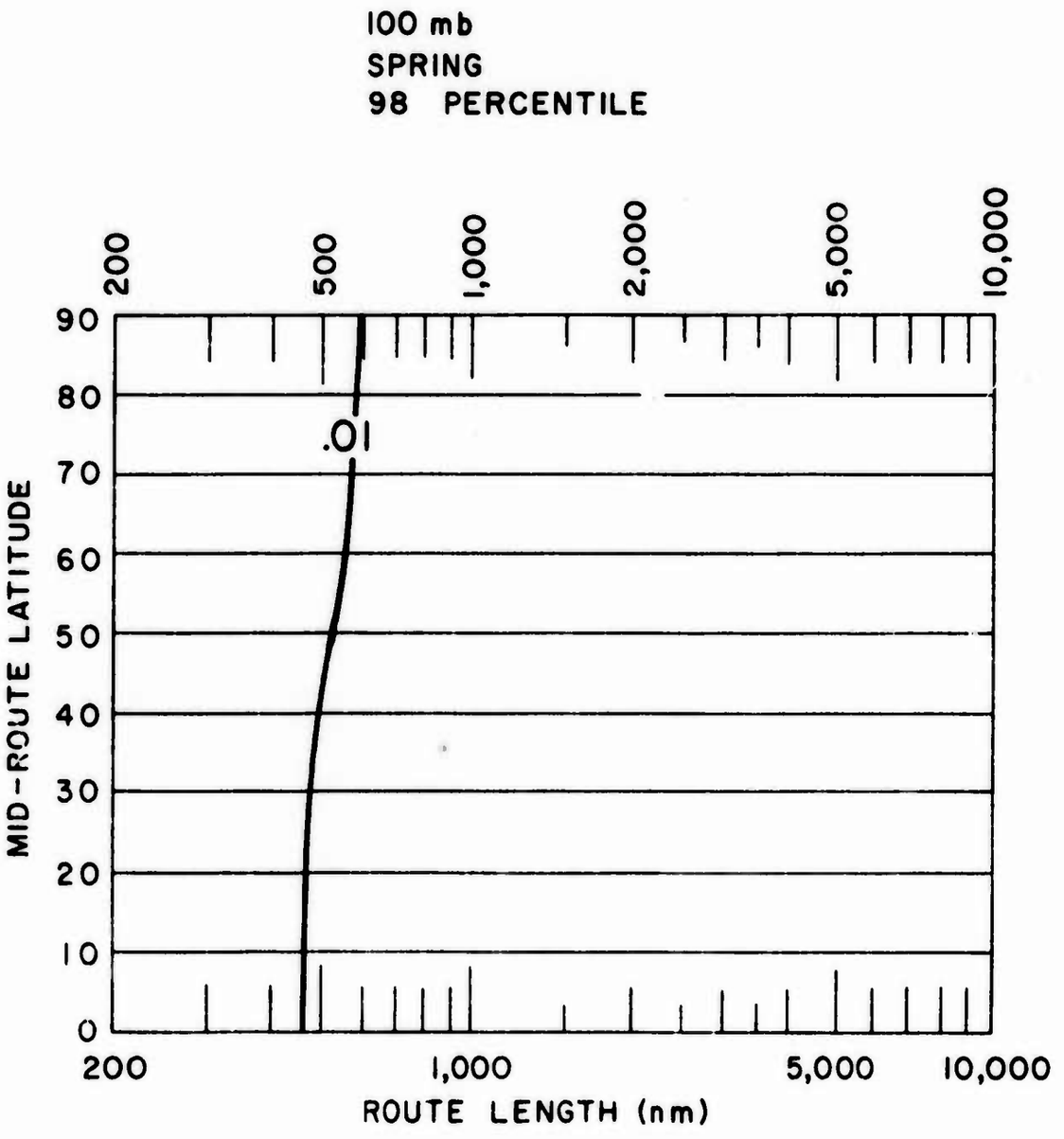


Plate 14. Temperature at 100 mb, in March, April, May, 98 Percentile



Graph 14. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

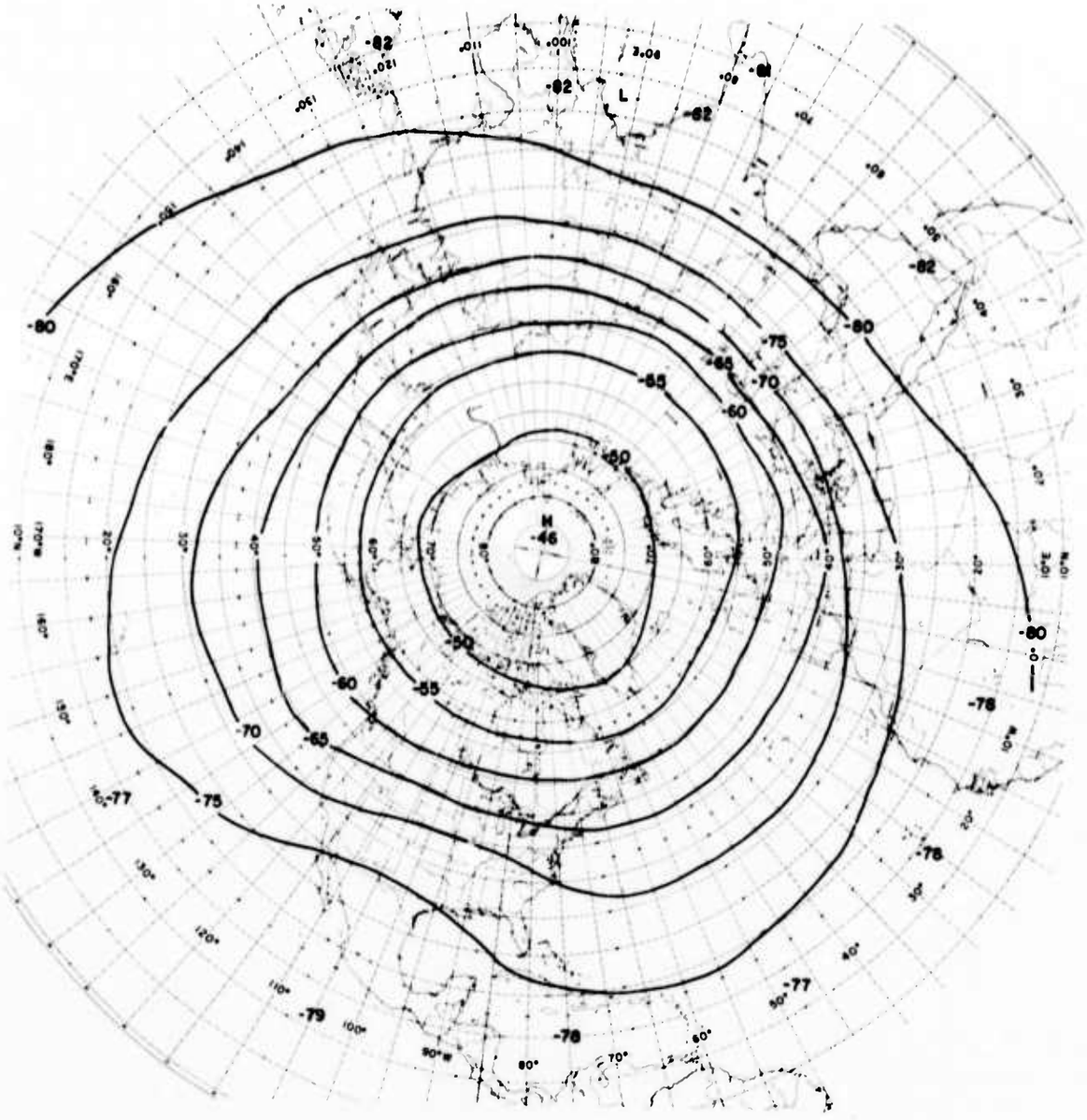
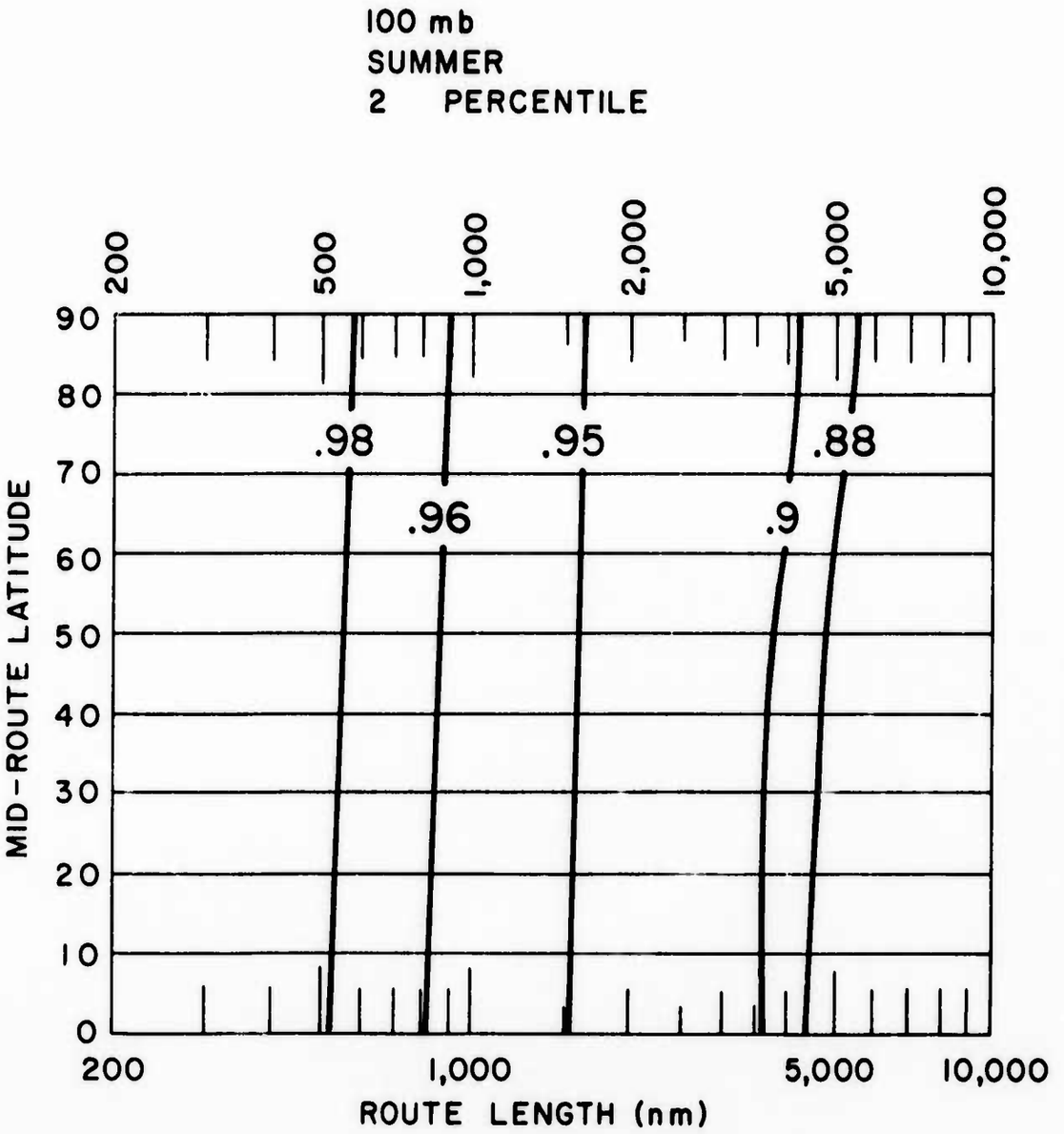


Plate 15. Temperature at 100 mb, in June, July, August, 2 Percentile



Graph 15. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

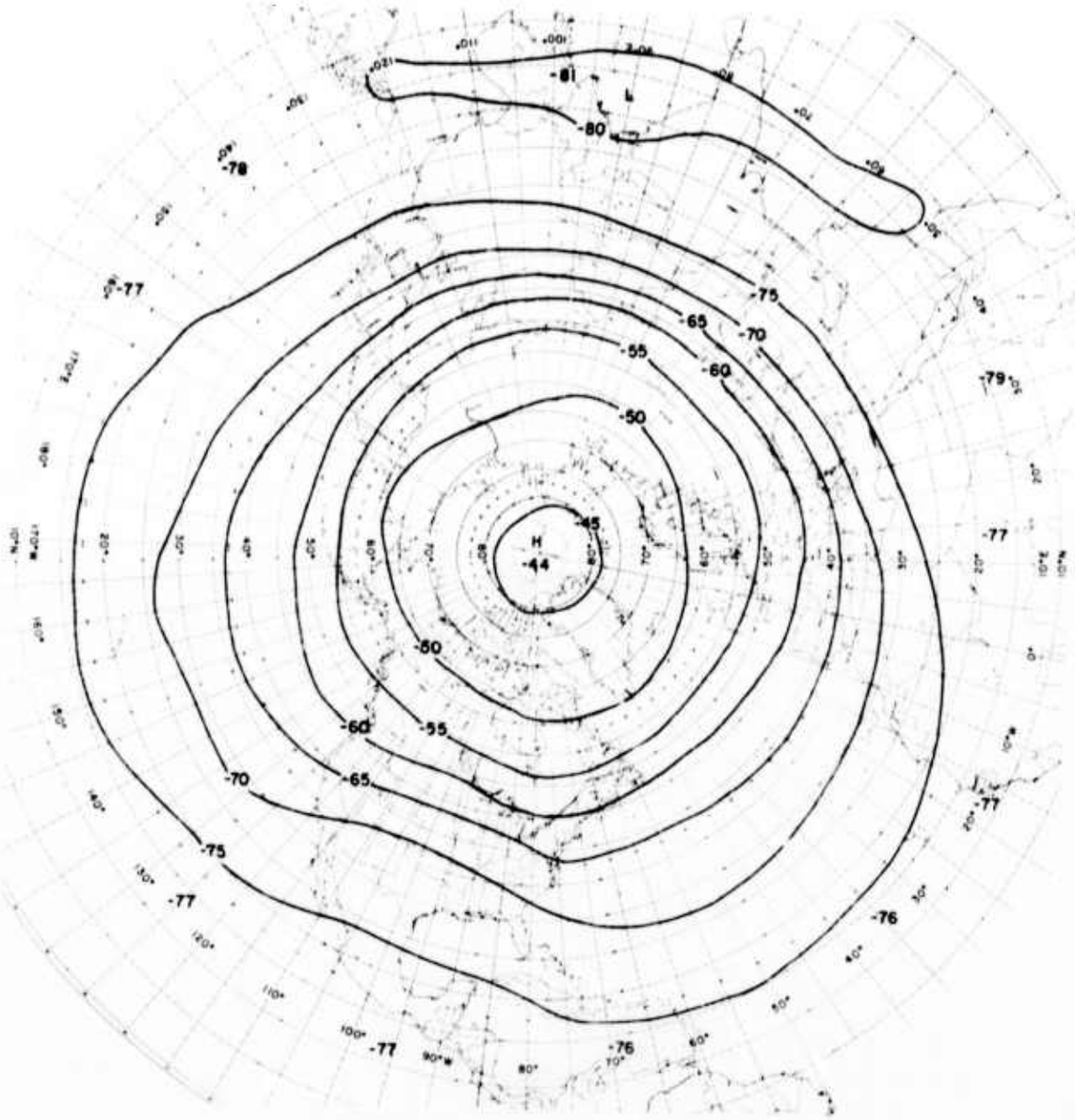
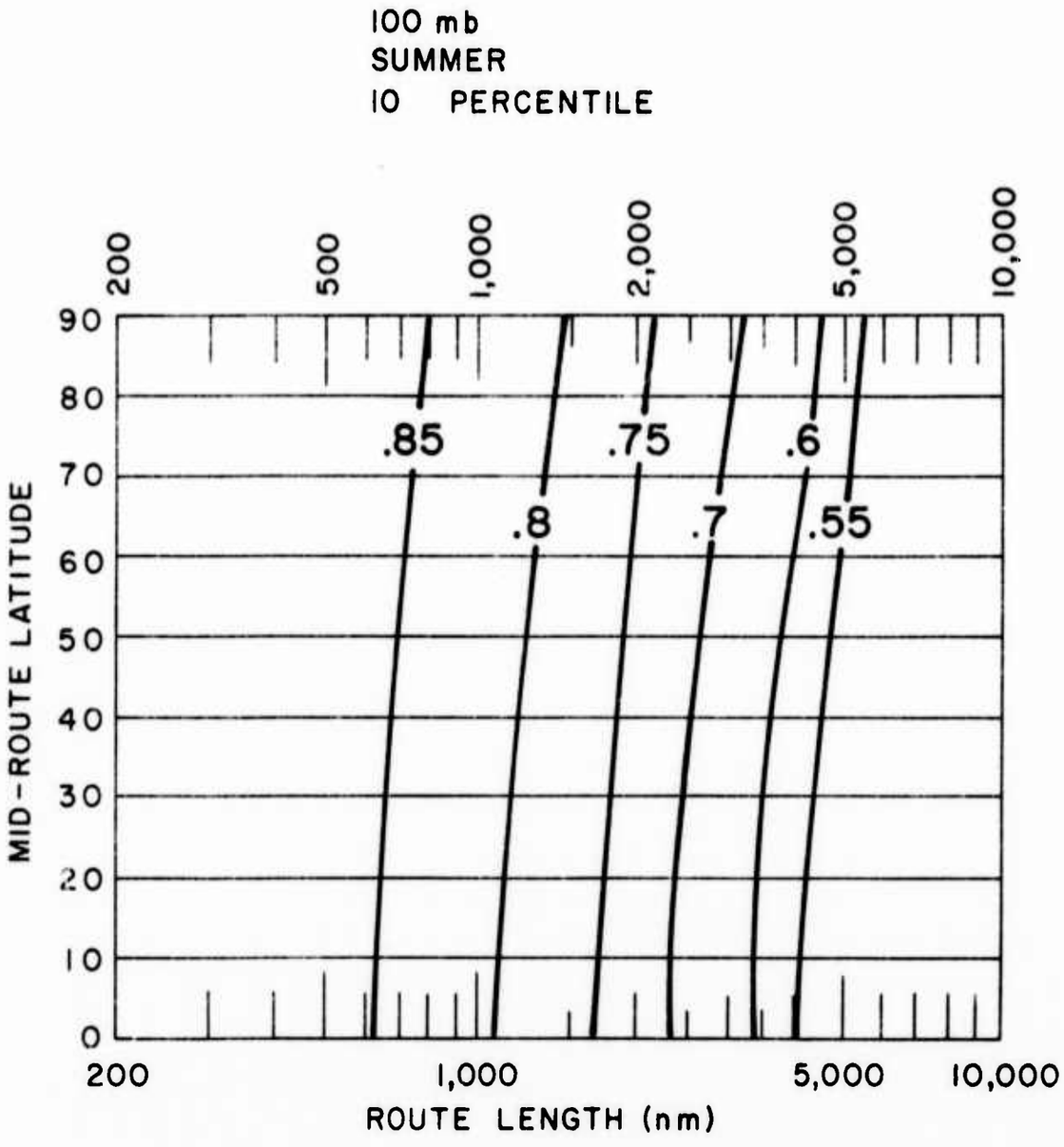


Plate 16. Temperature at 100 mb, in June, July, August, 10 Percentile



Graph 16. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

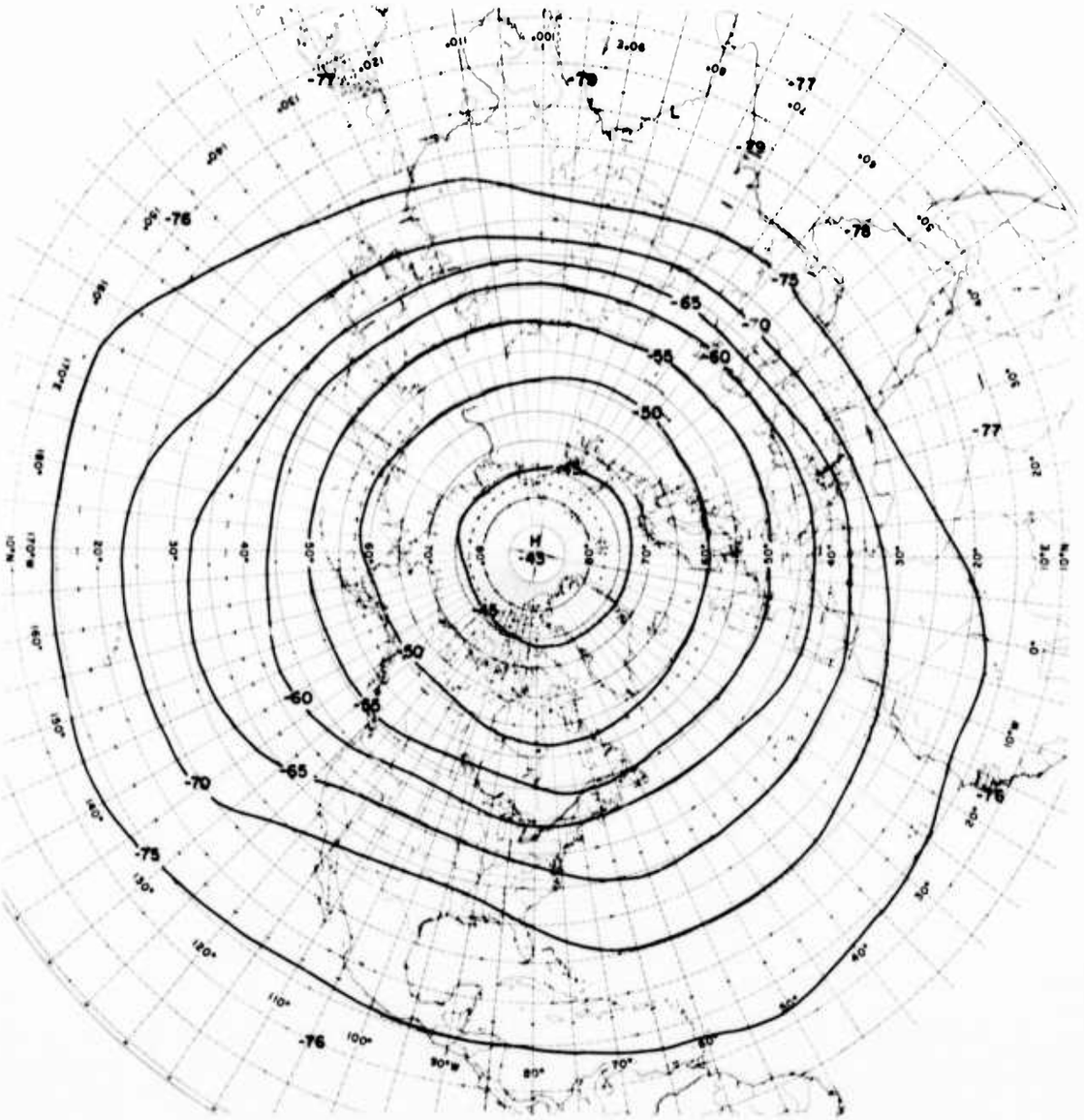
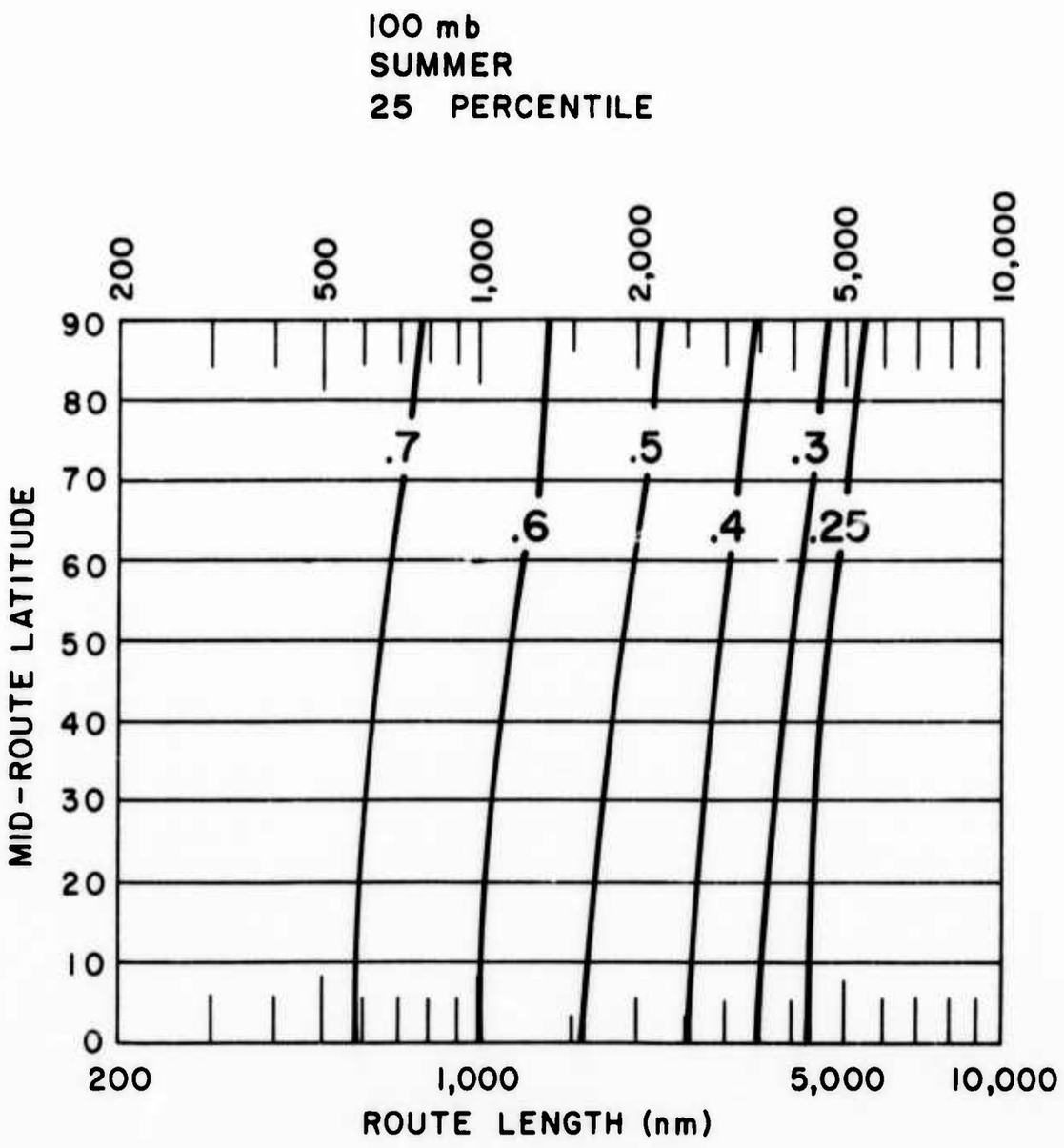


Plate 17. Temperature at 100 mb, in June, July, August, 25 Percentile



Graph 17. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

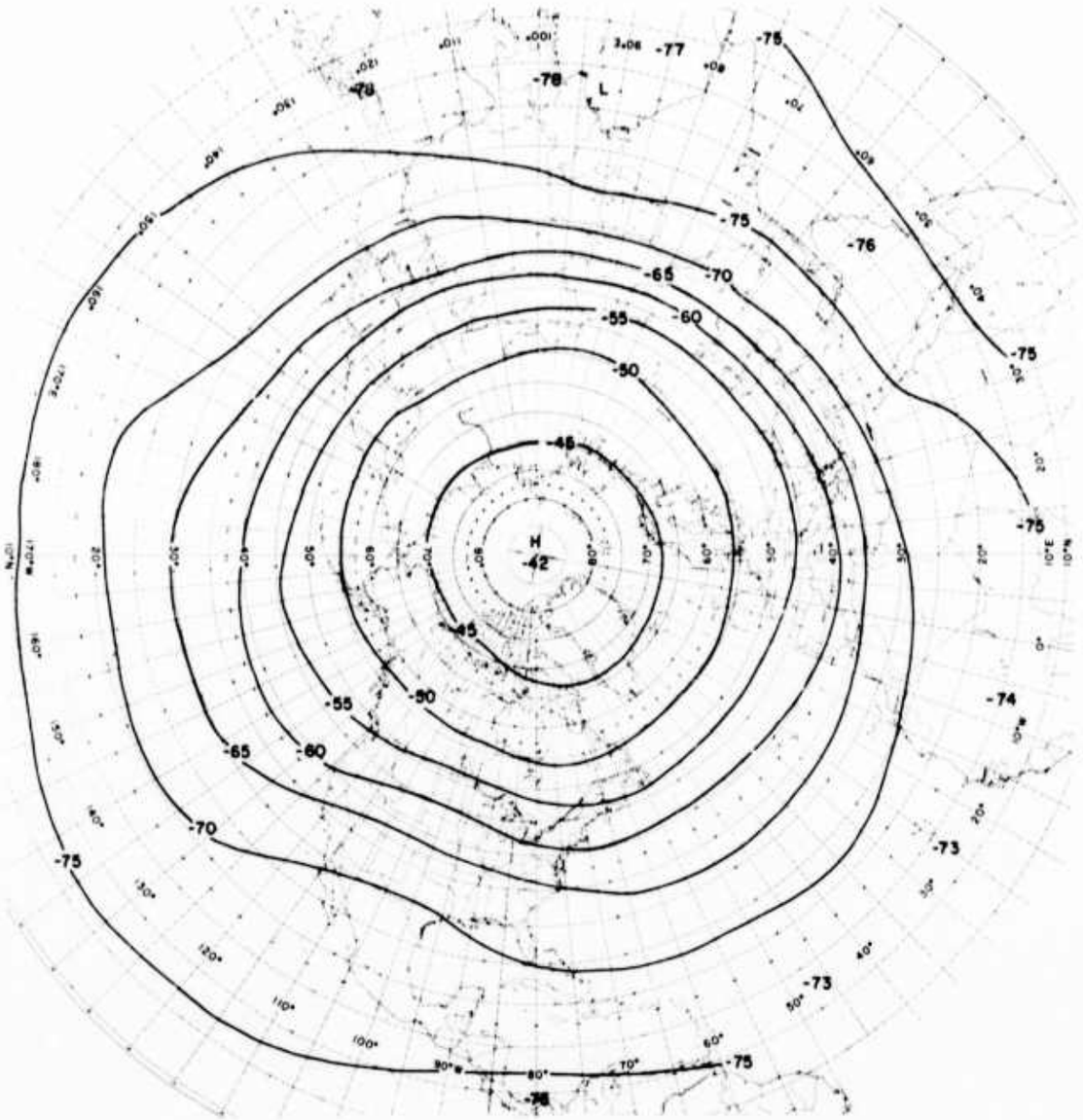
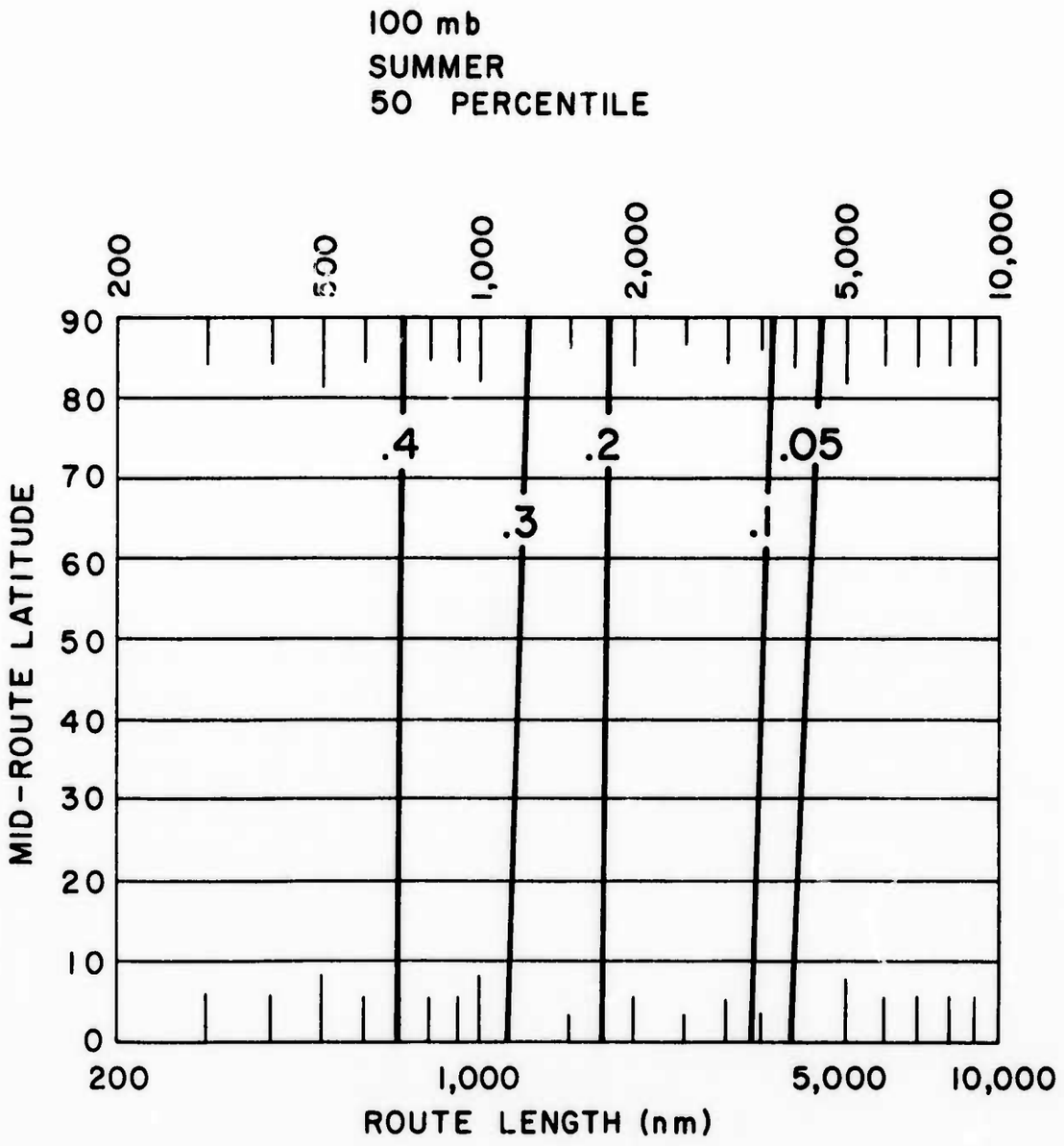


Plate 18. Temperature at 100 mb, in June, July, August, 50 Percentile



Graph 18. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

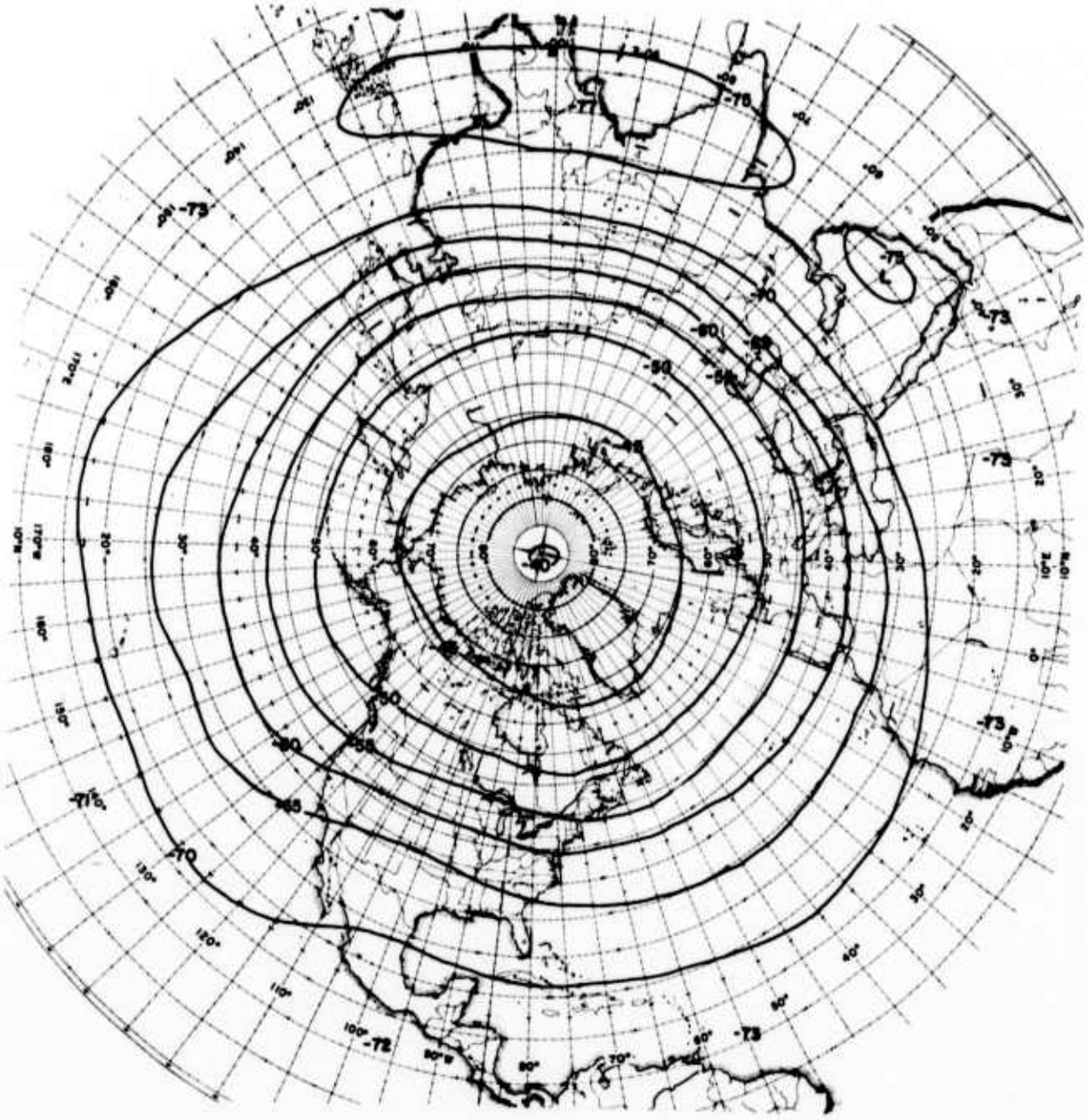
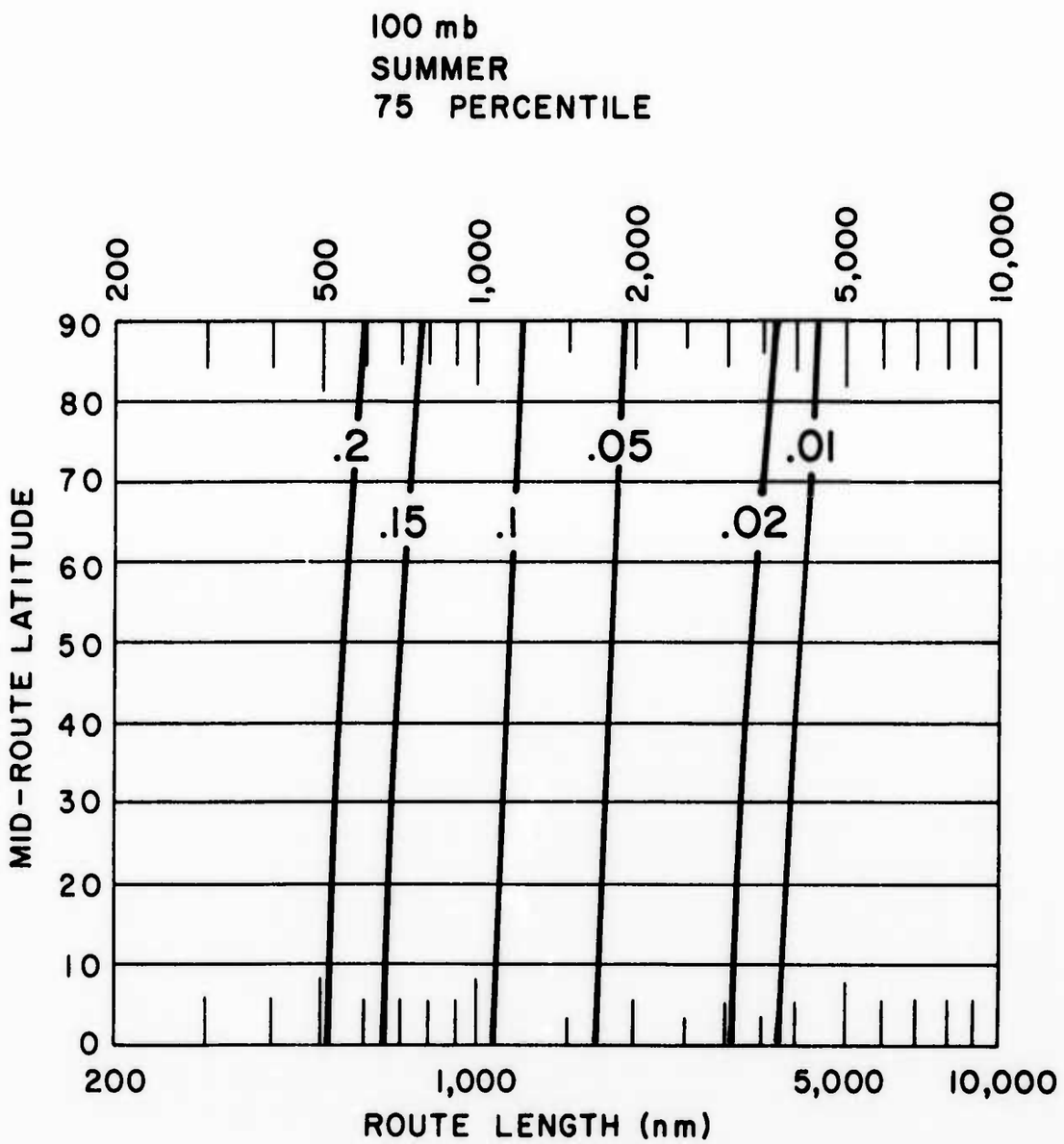


Plate 19. Temperature at 100 mb, in June, July, August, 75 Percentile



Graph 19. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

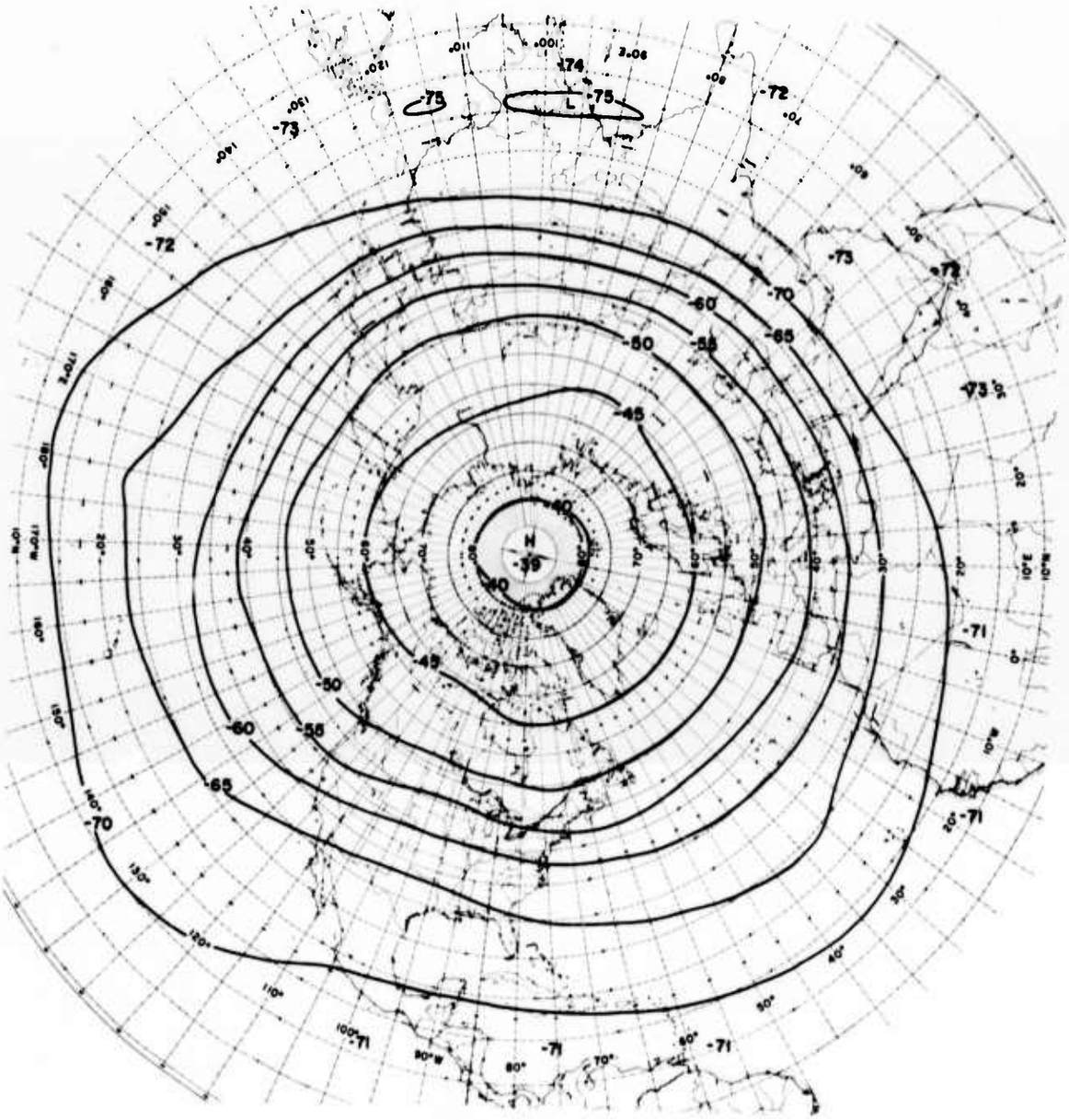
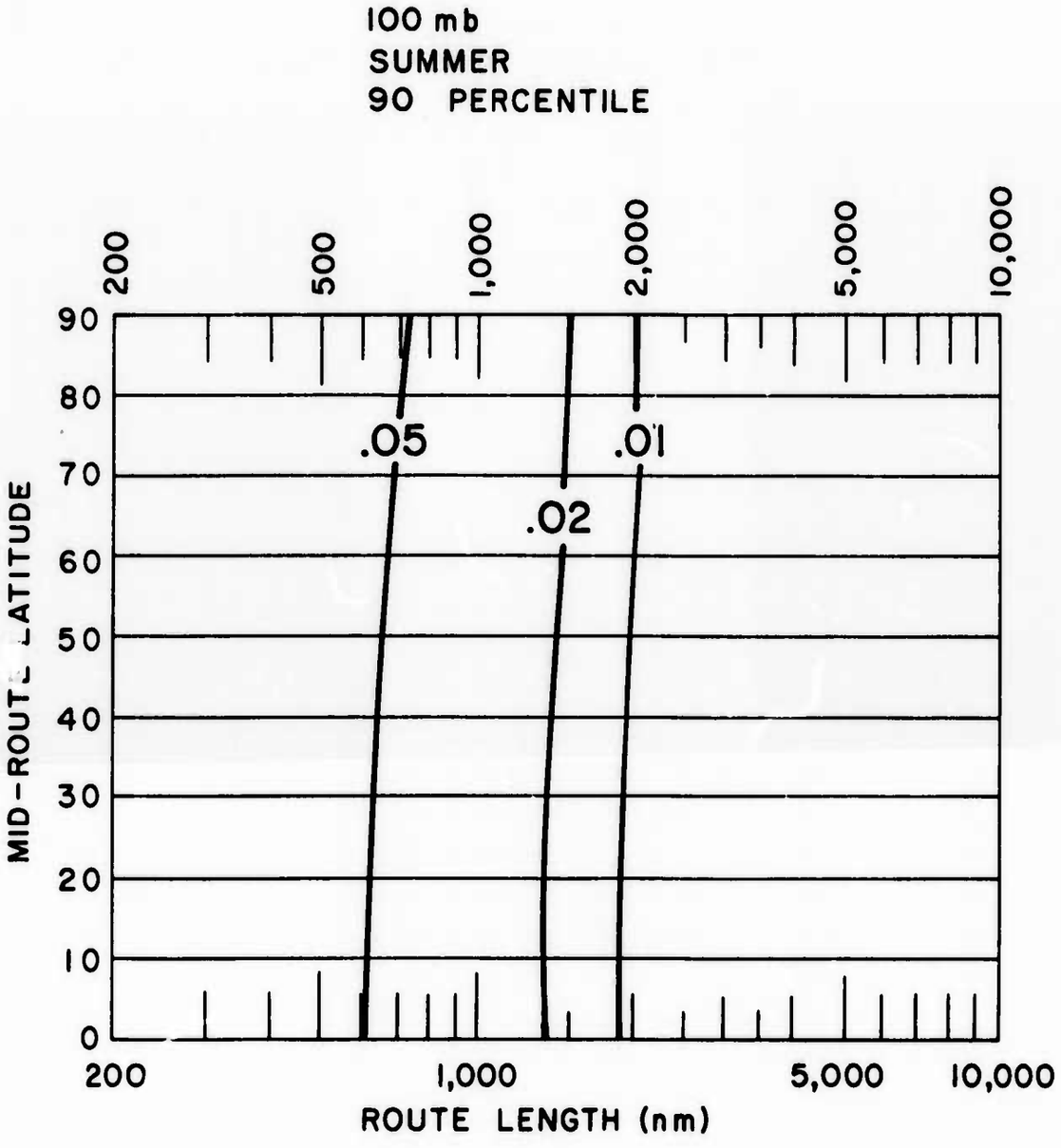
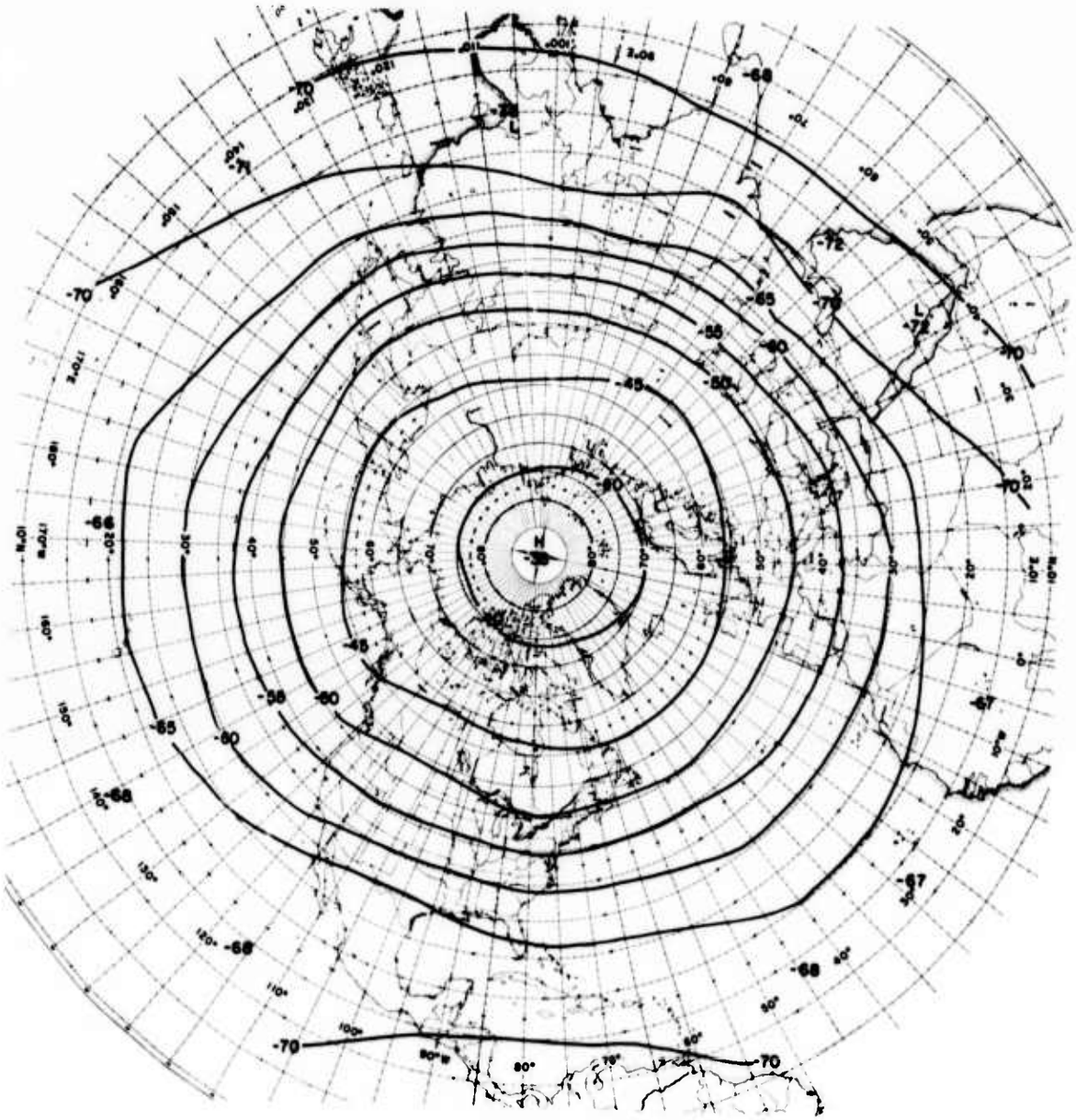


Plate 20. Temperature at 100 mb, in June, July, August, 90 Percentile



Graph 20. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page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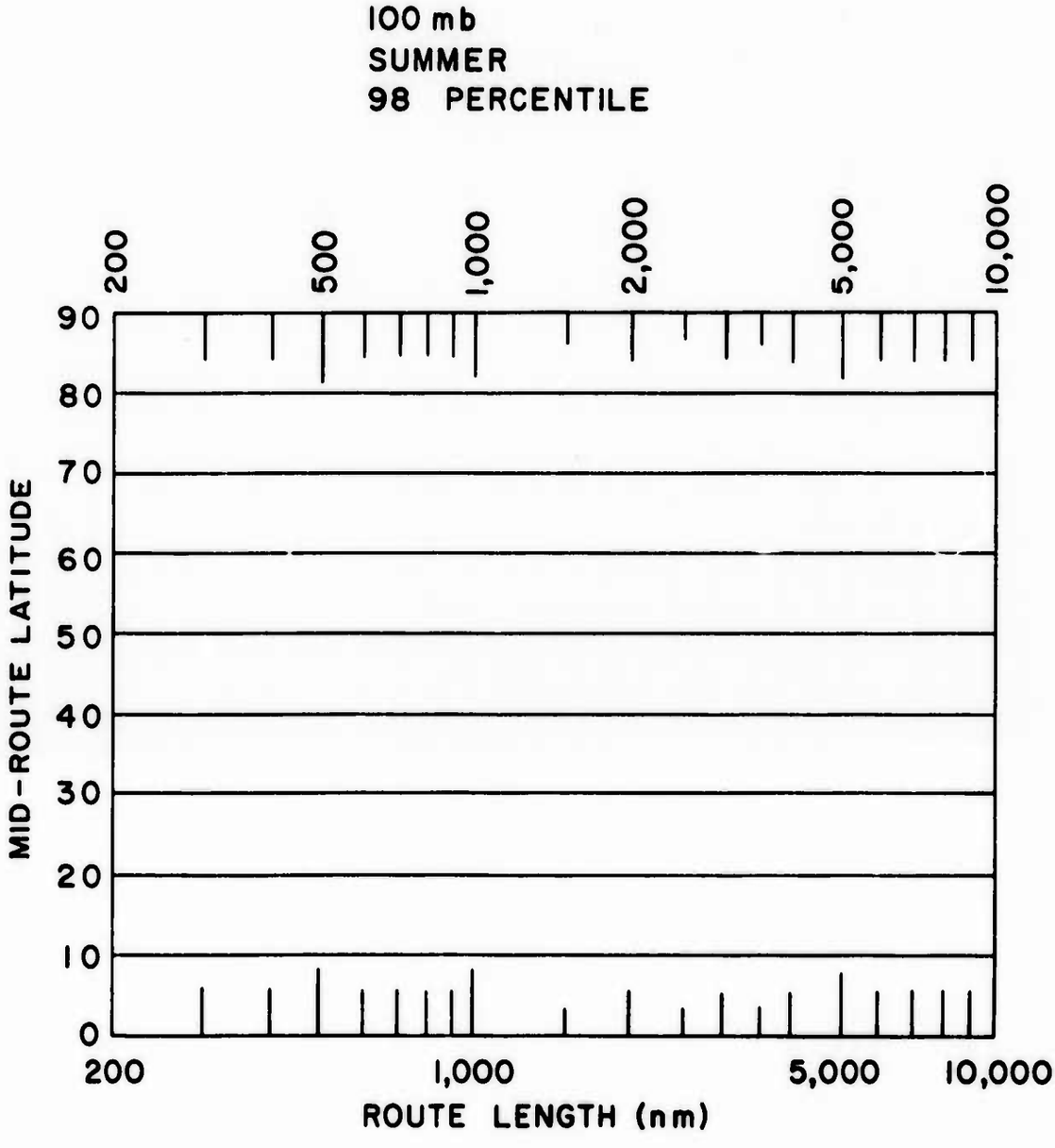


Graph 21. Negligible Probabilities

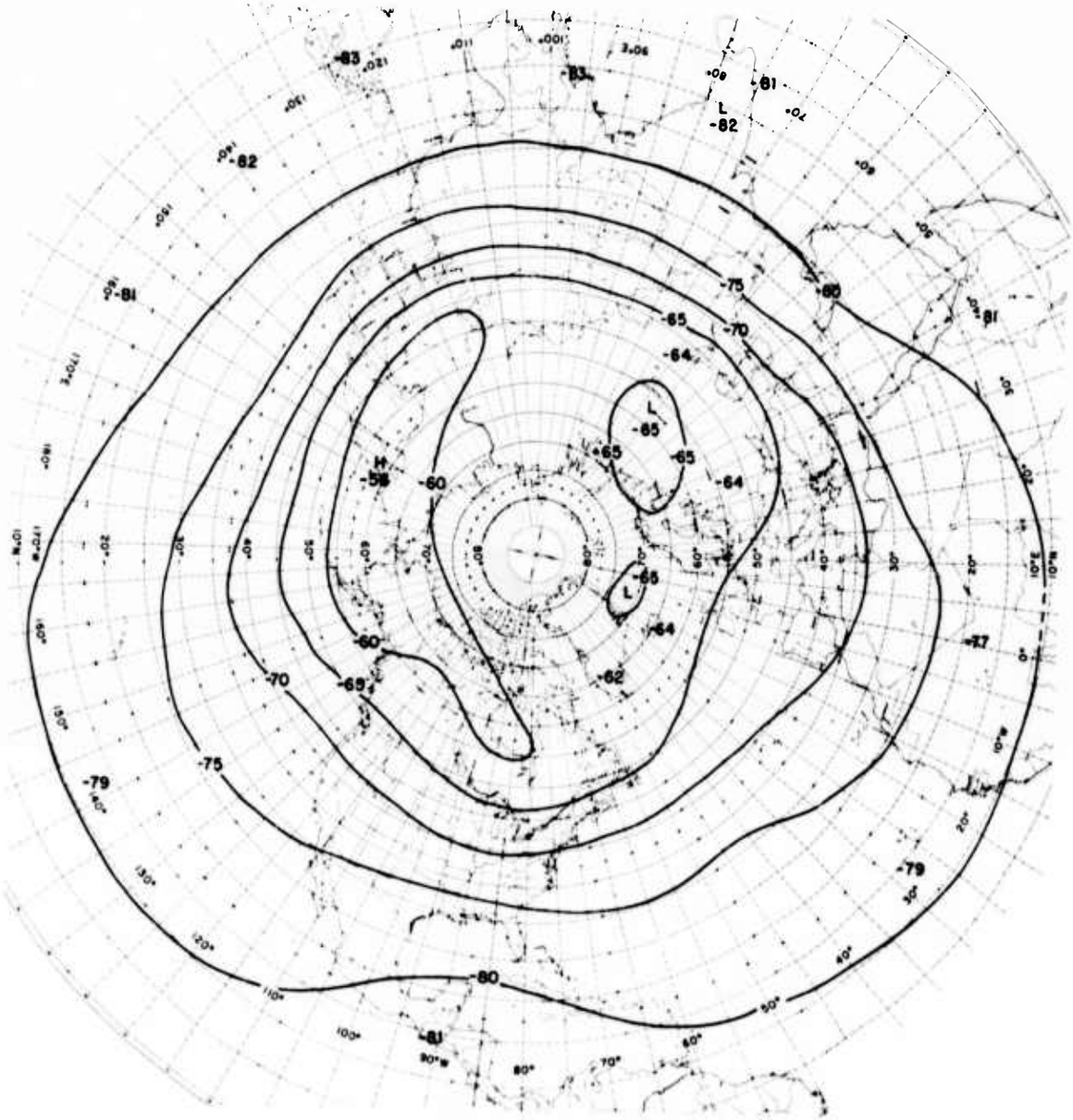
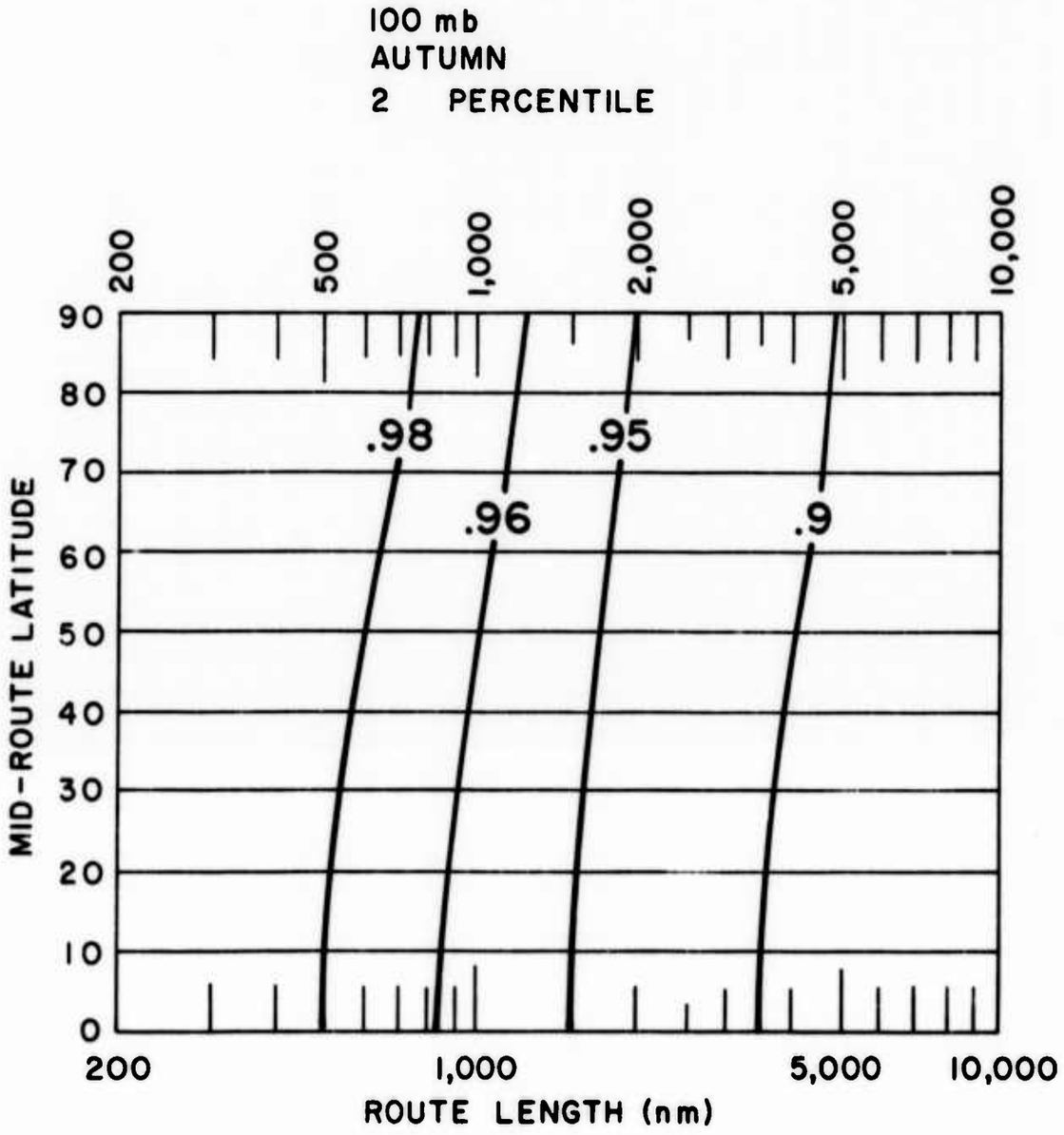


Plate 22. Temperature at 100 mb, in September, October, November, 2 Percentile



Graph 22. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

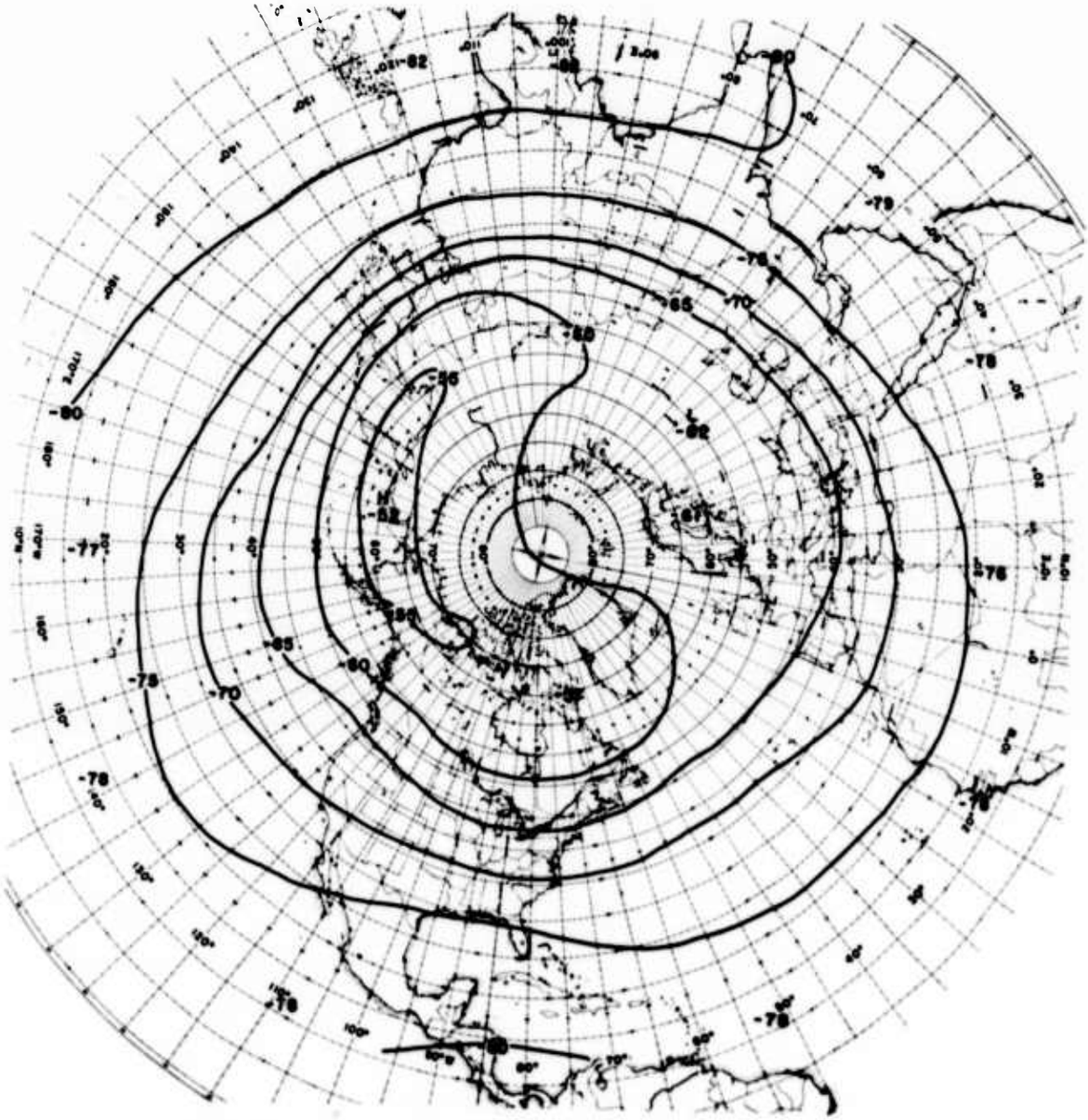
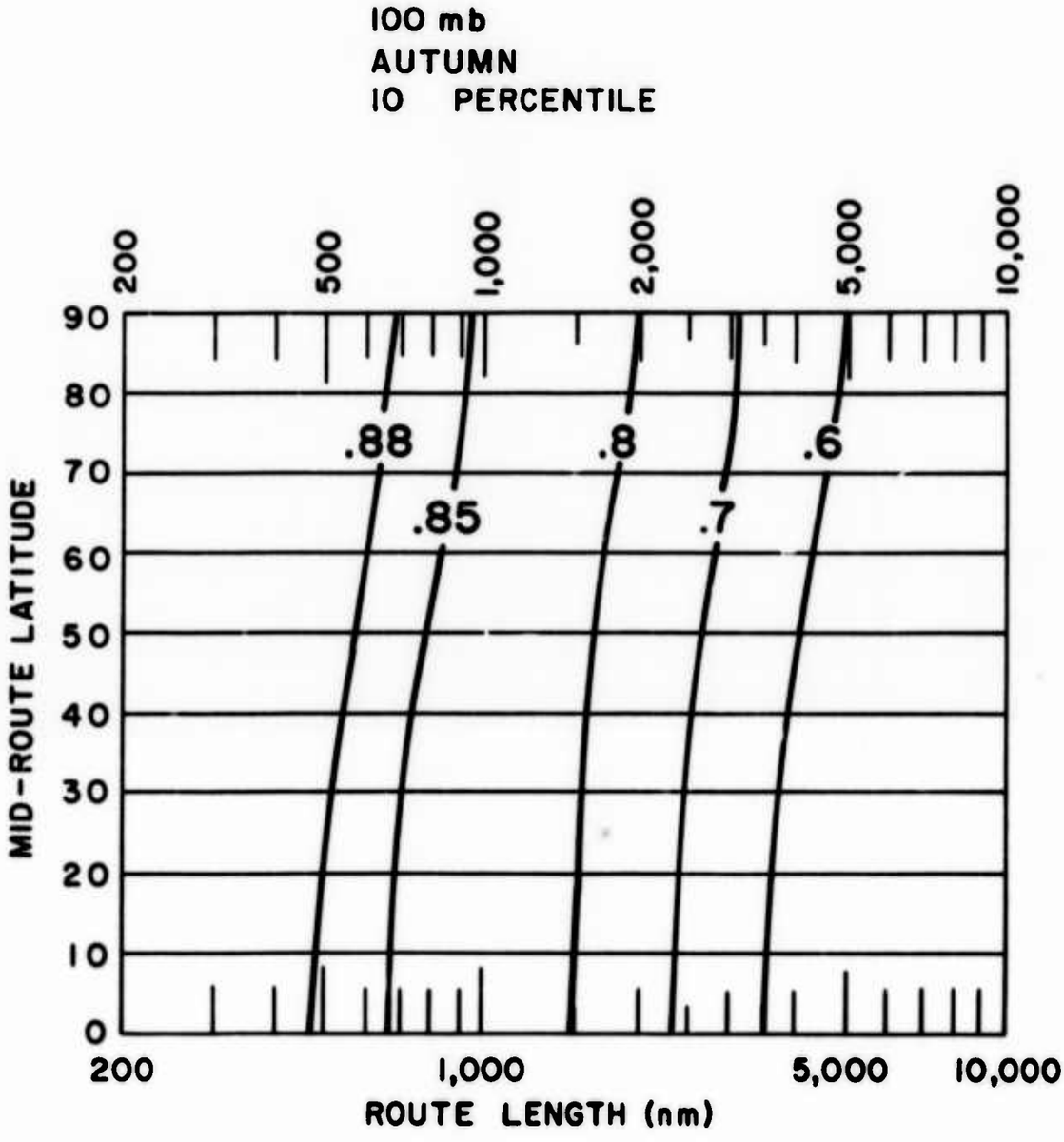


Plate 23. Temperature at 100 mb, in September, October, November, 10 Percentile



Graph 23. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

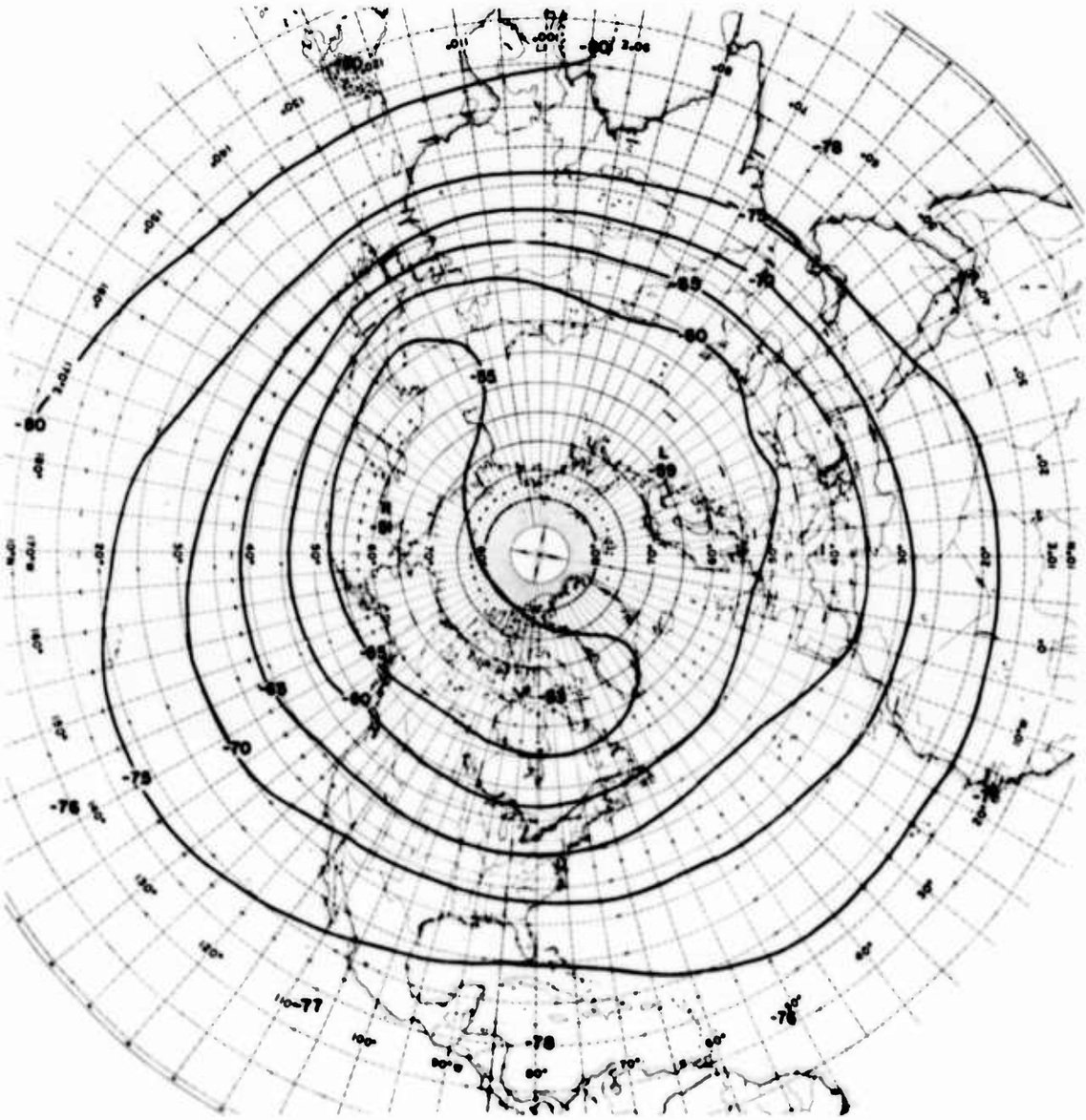
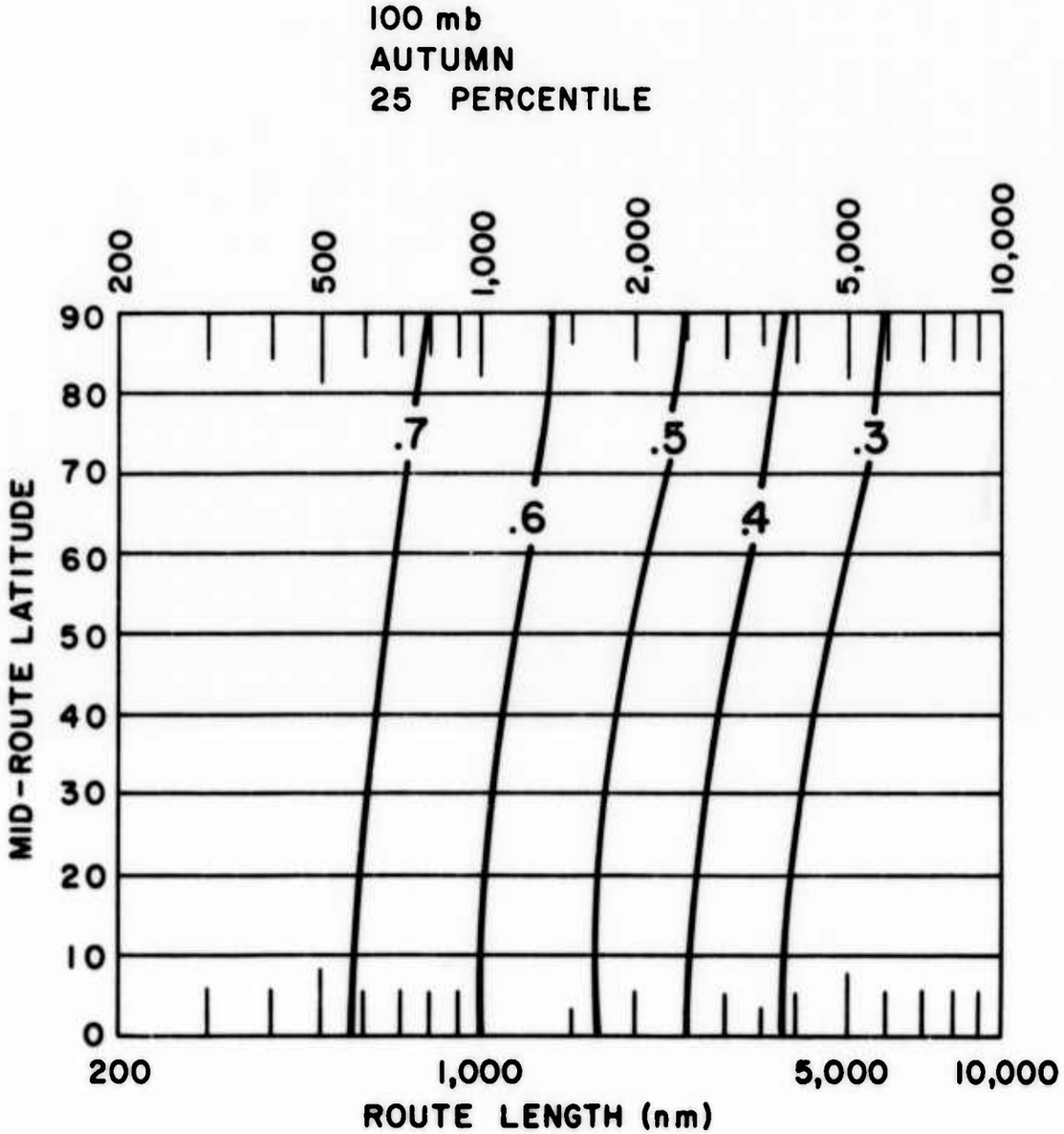


Plate 24. Temperature at 100 mb, in September, October, November, 25 Percentile



Graph 24. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

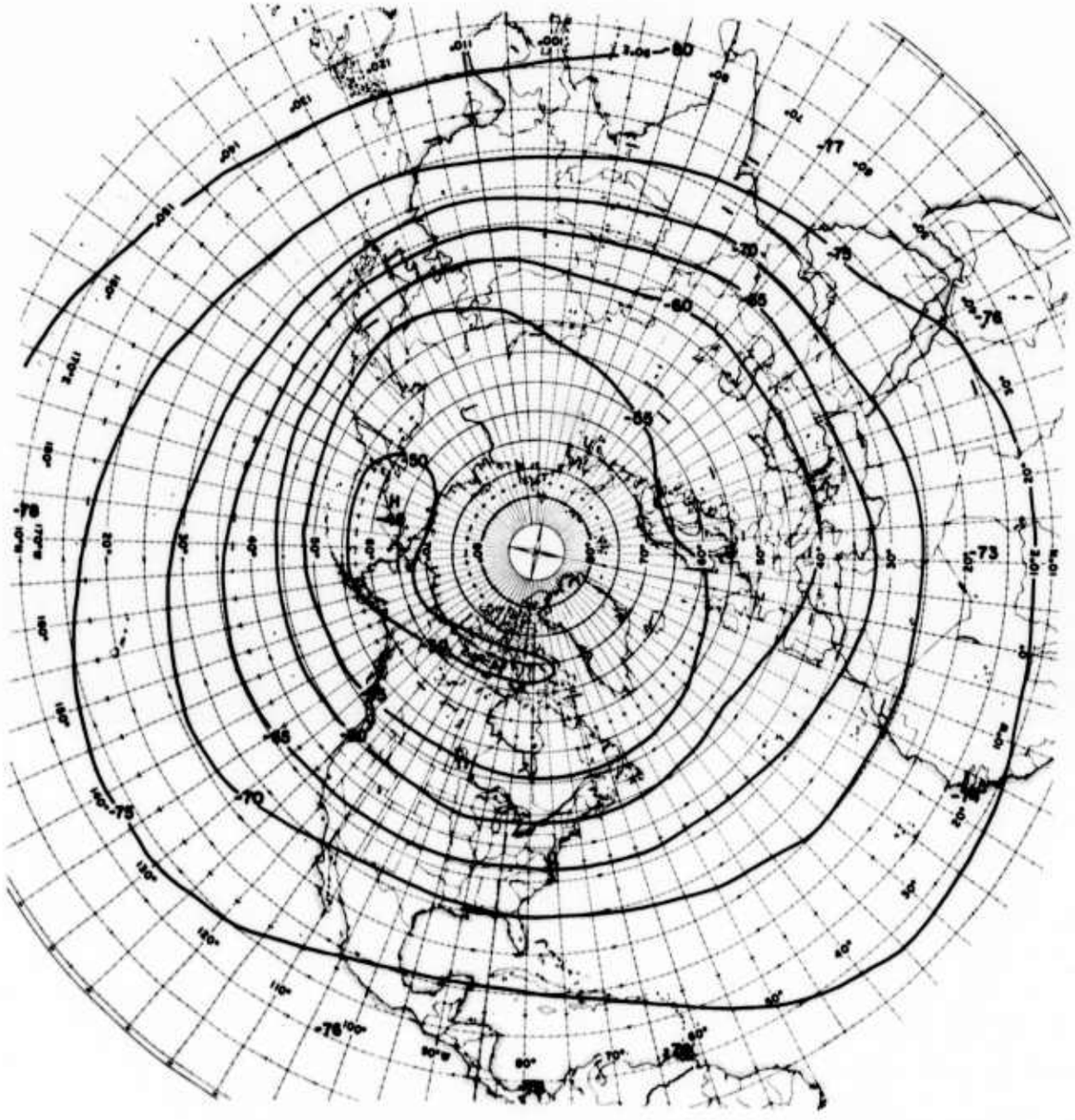
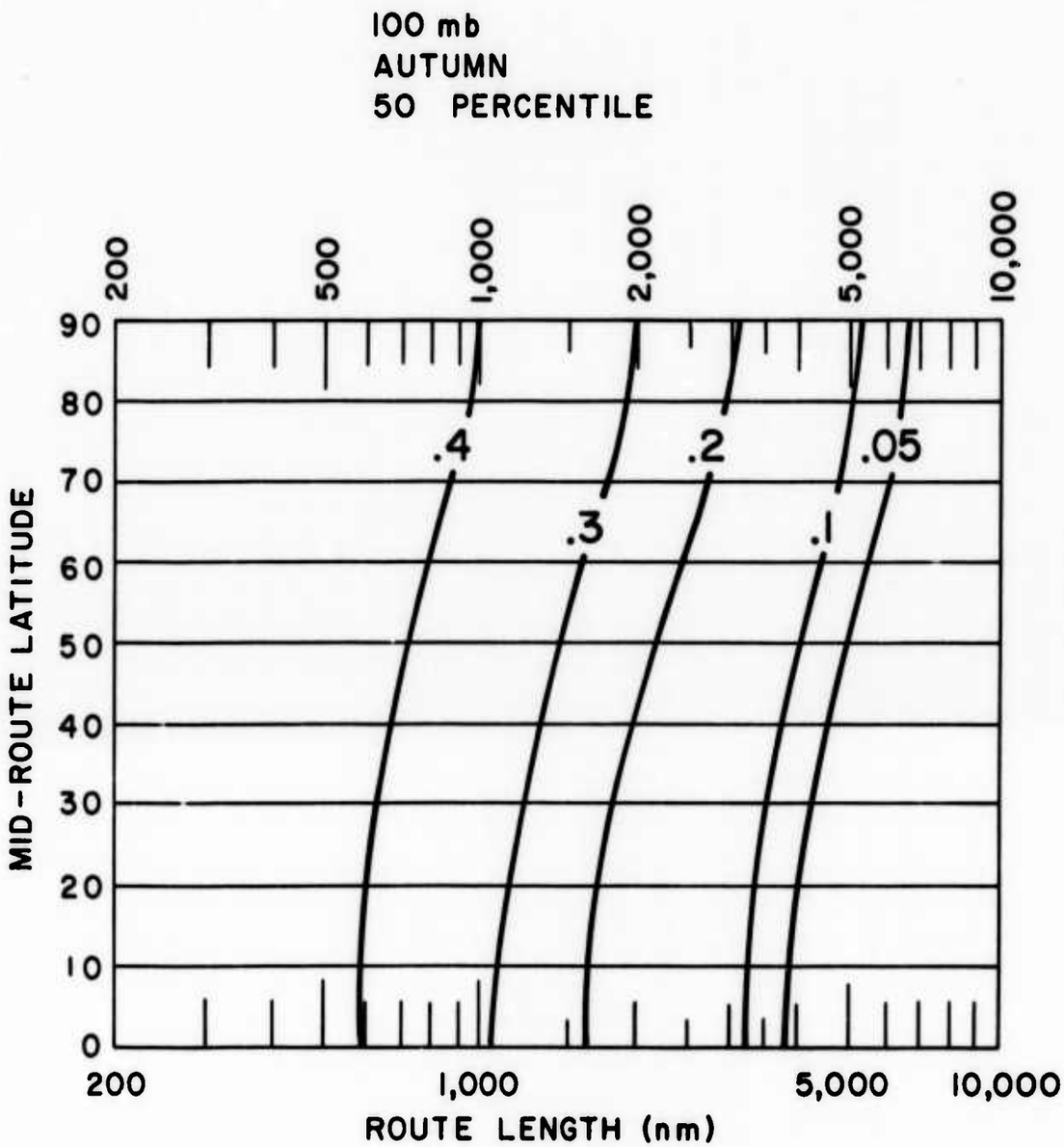


Plate 25. Temperature at 100 mb, in September, October, November, 50 Percentile



Graph 25. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

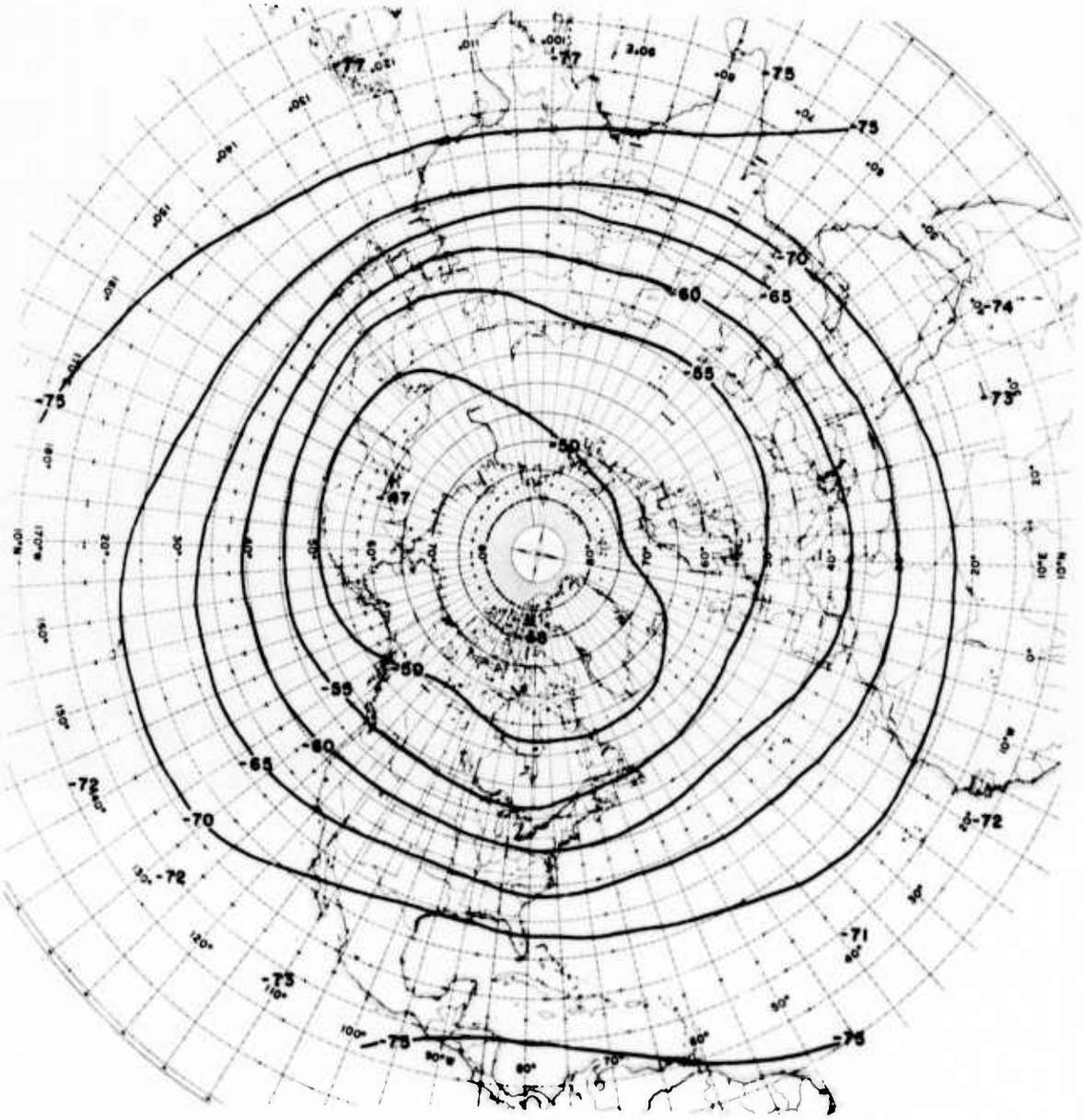
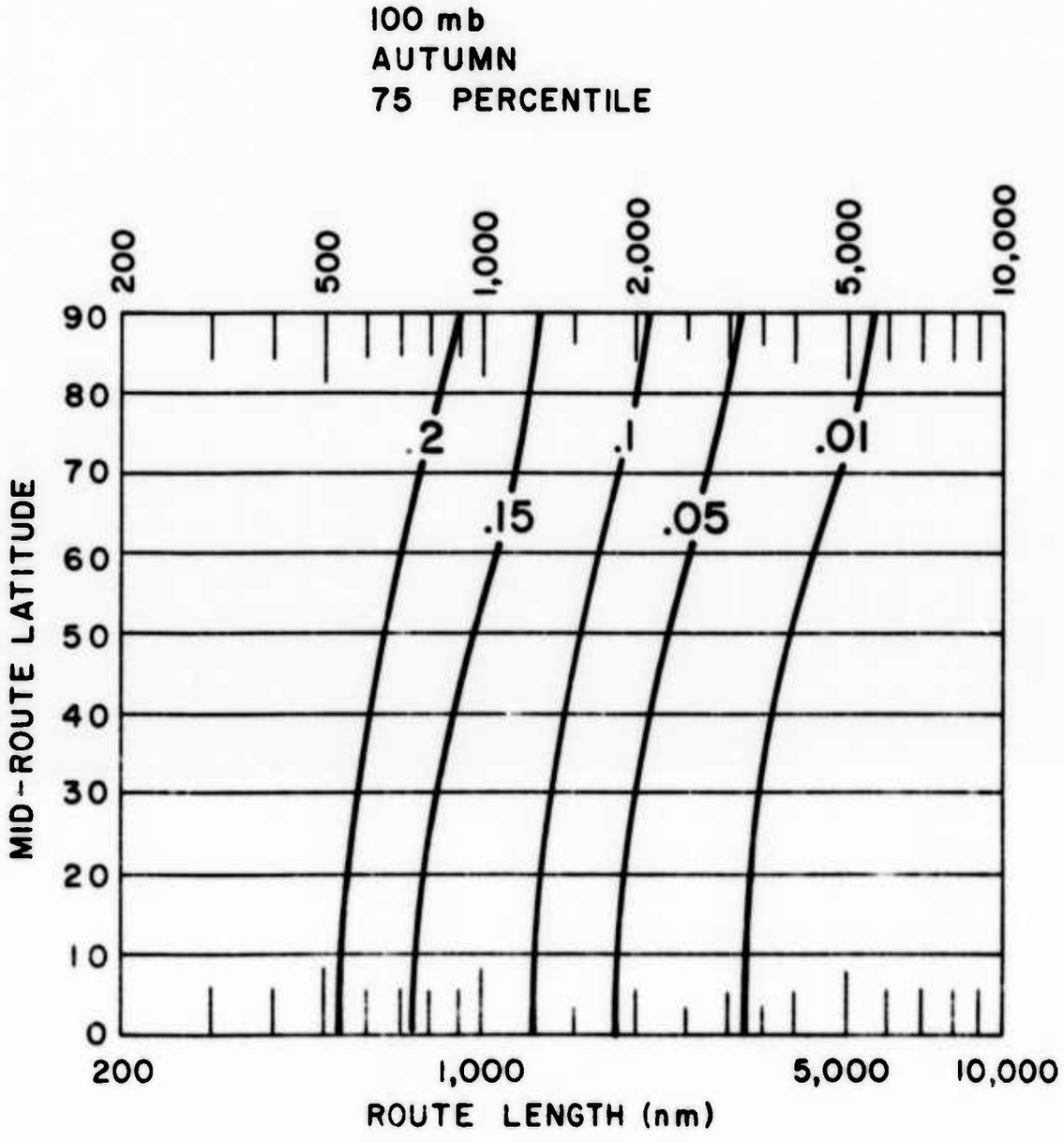


Plate 26. Temperature at 100 mb, in September, October, November, 75 Percentile



Graph 26. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

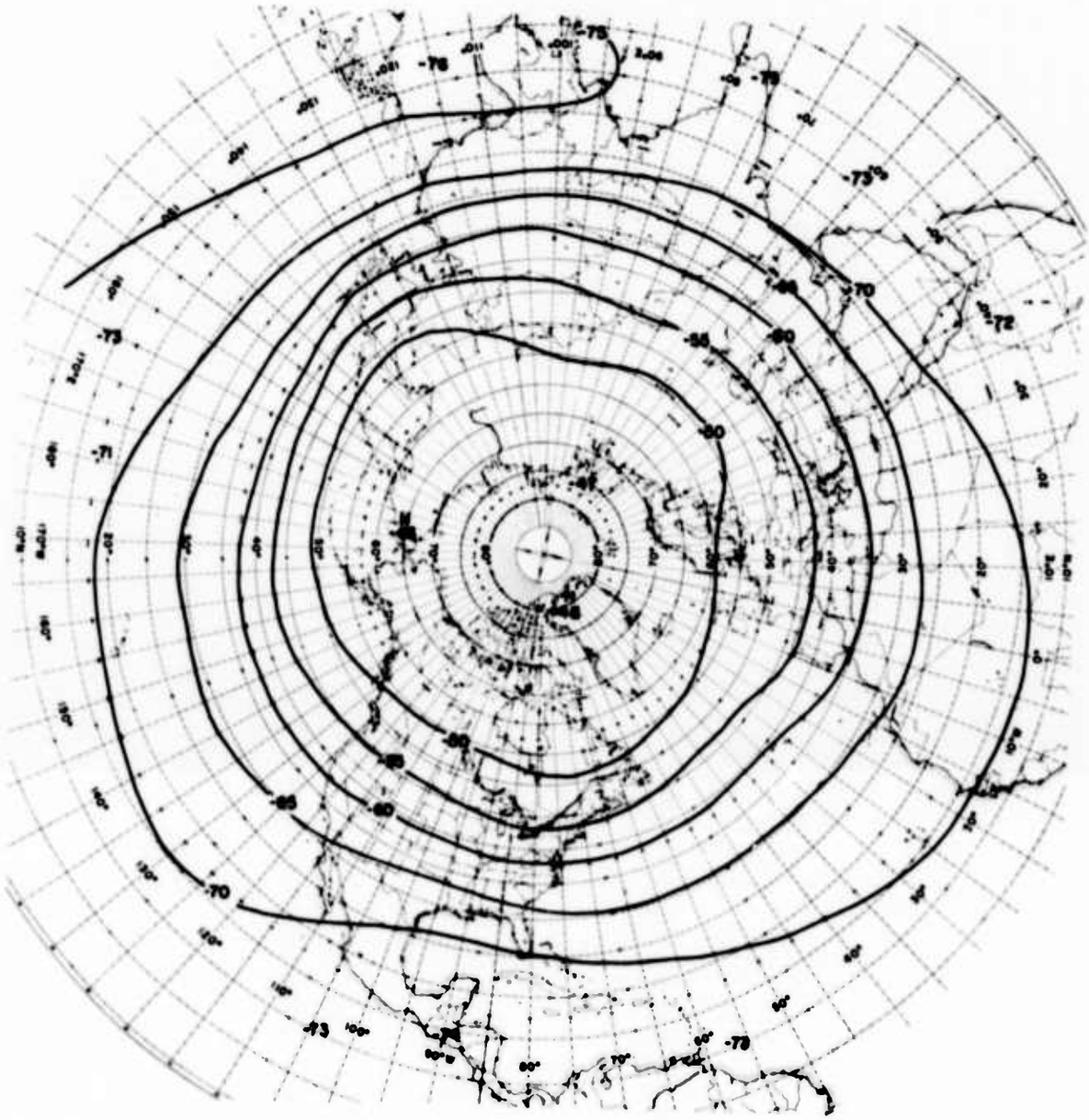
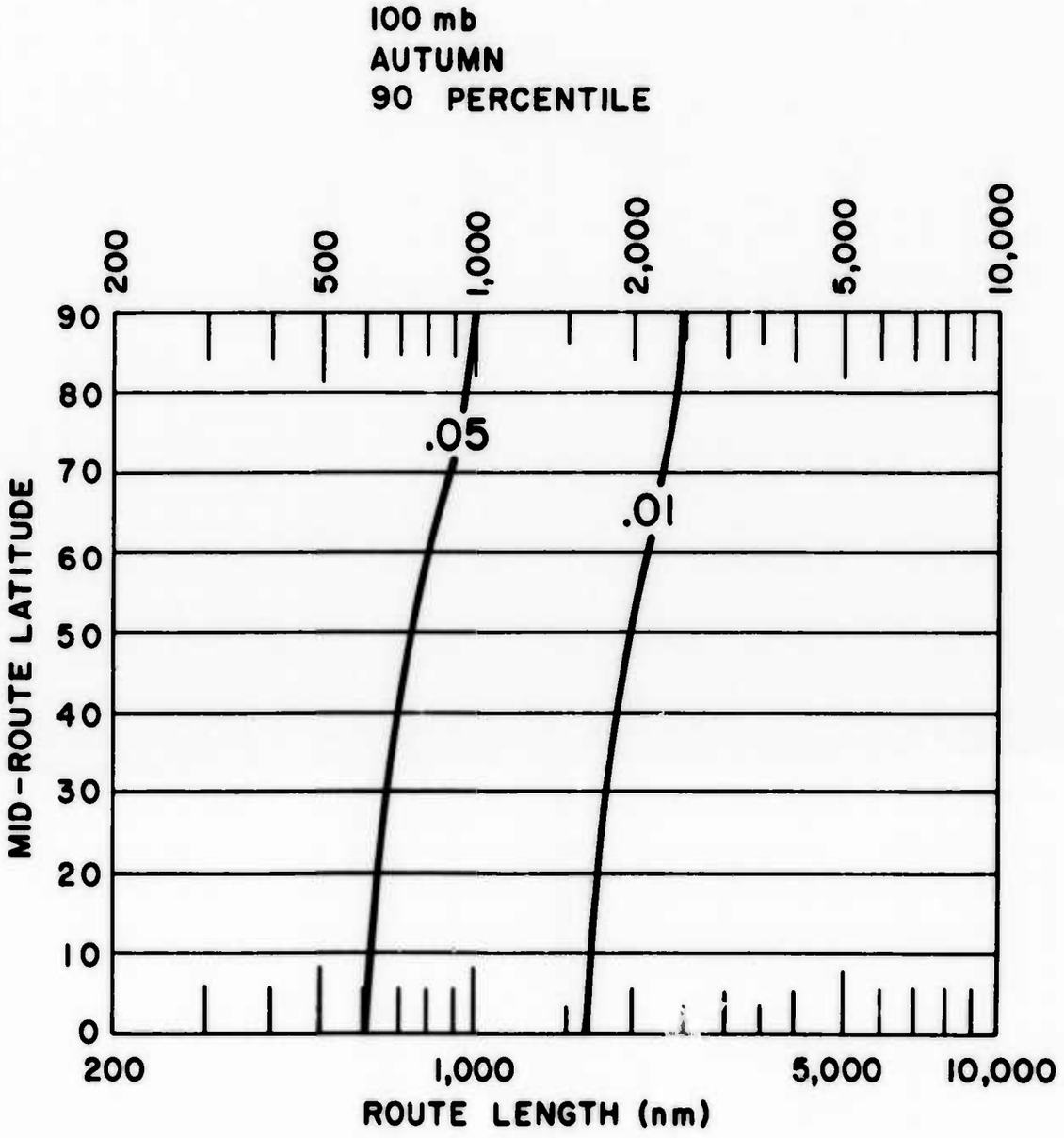


Plate 27. Temperature at 100 mb, in September, October, November, 90 Percentile



Graph 27. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

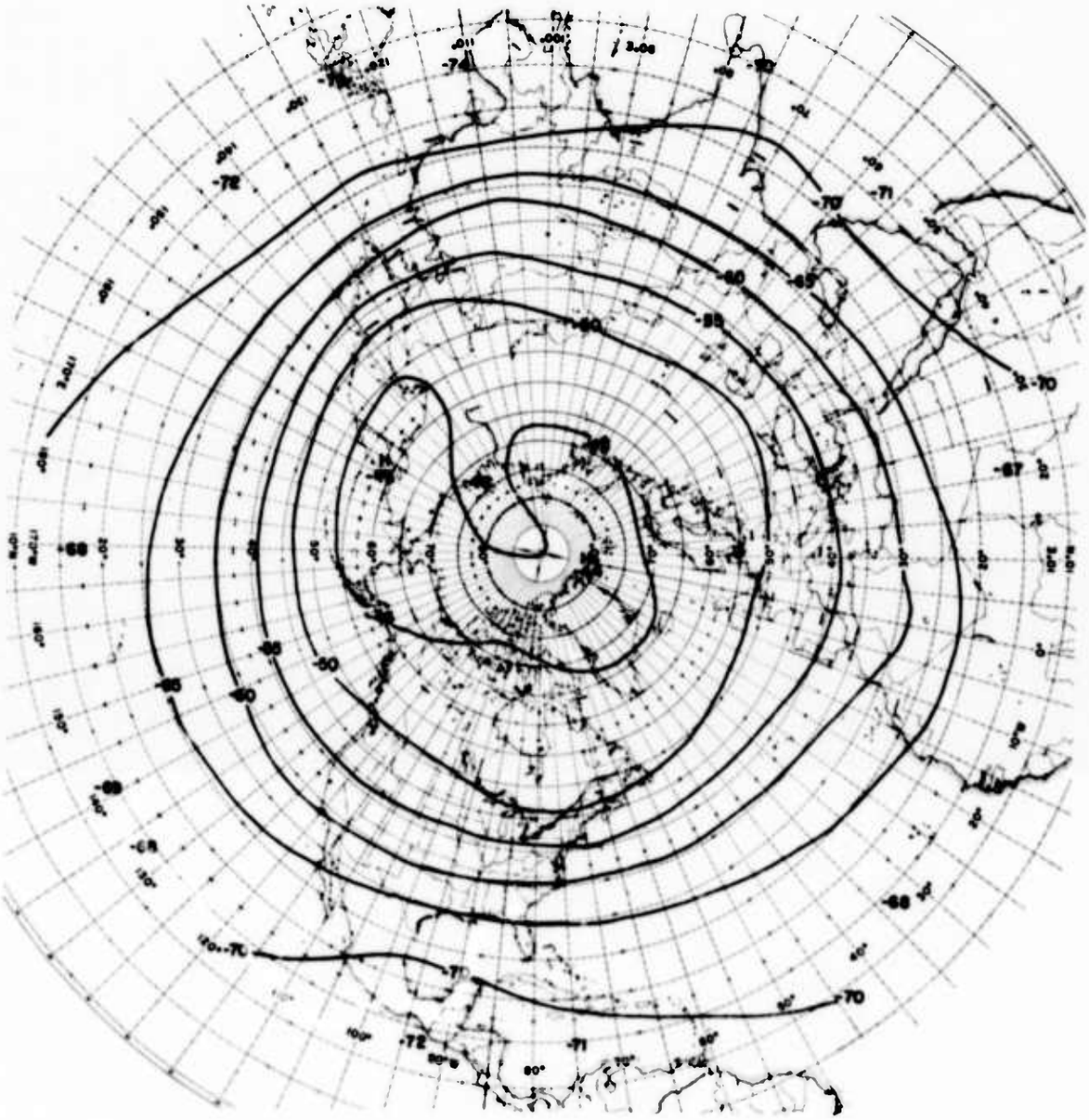
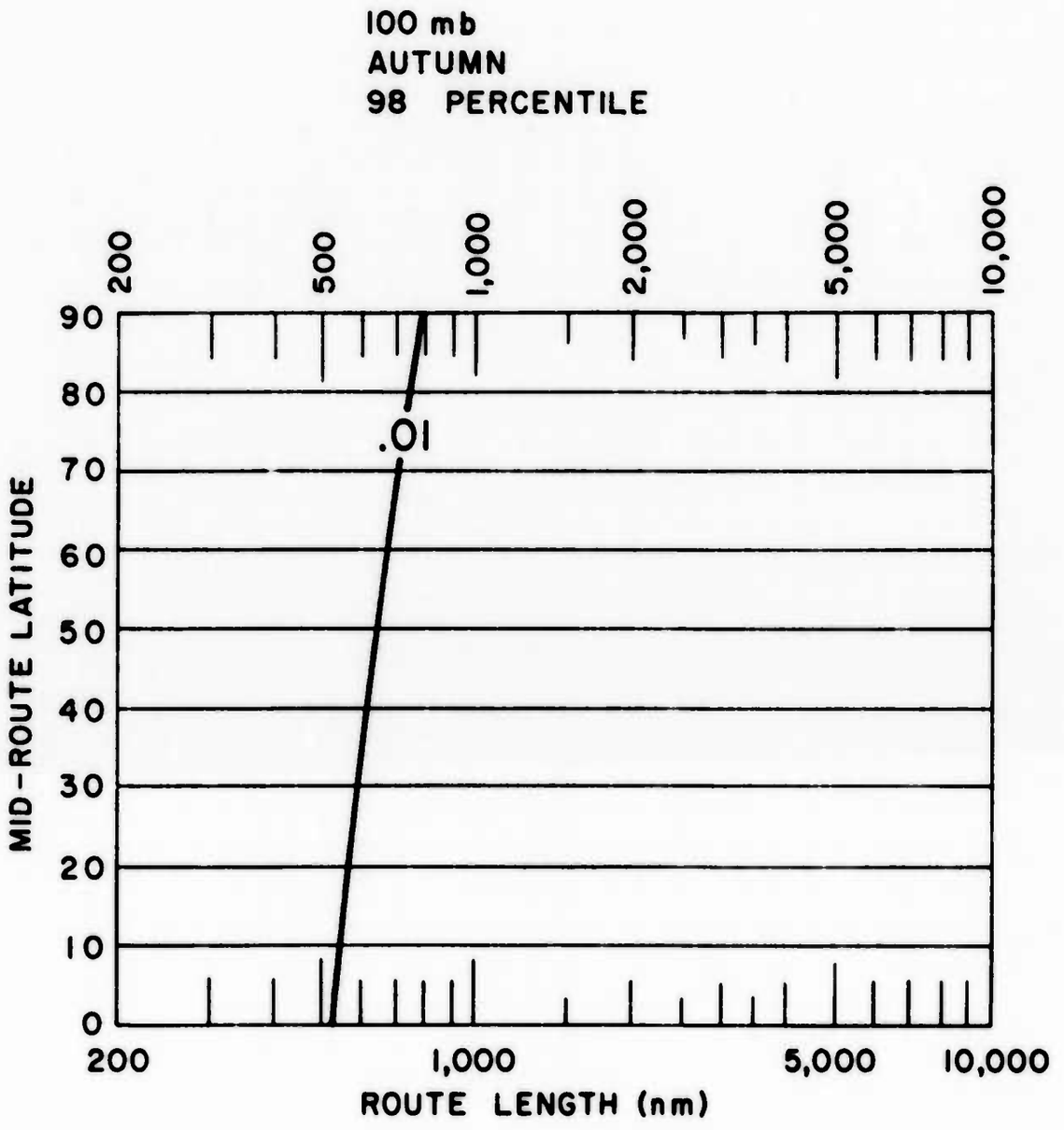


Plate 28. Temperature at 100 mb, in September, October, November, 98 Percentile



Graph 28. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

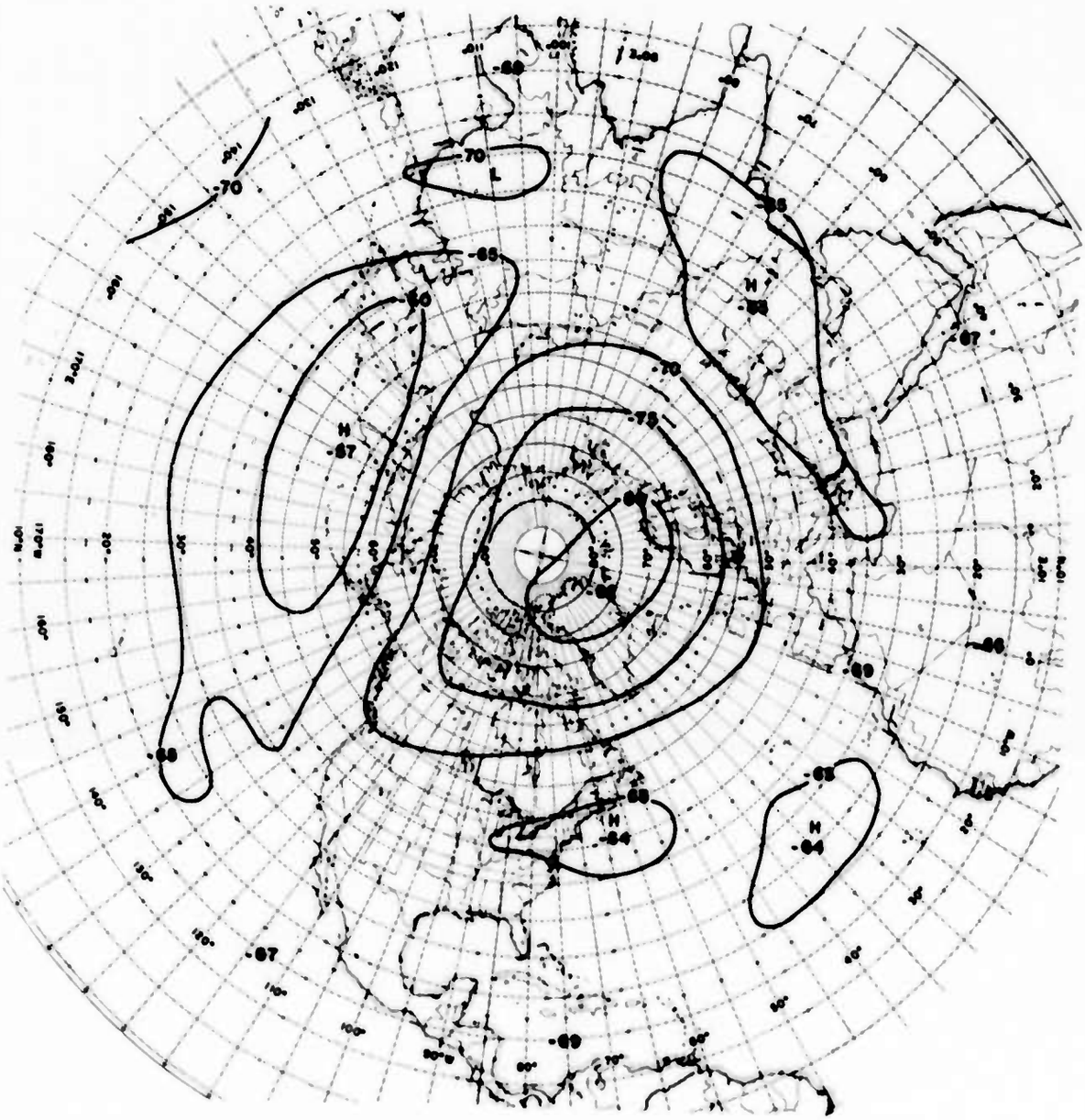
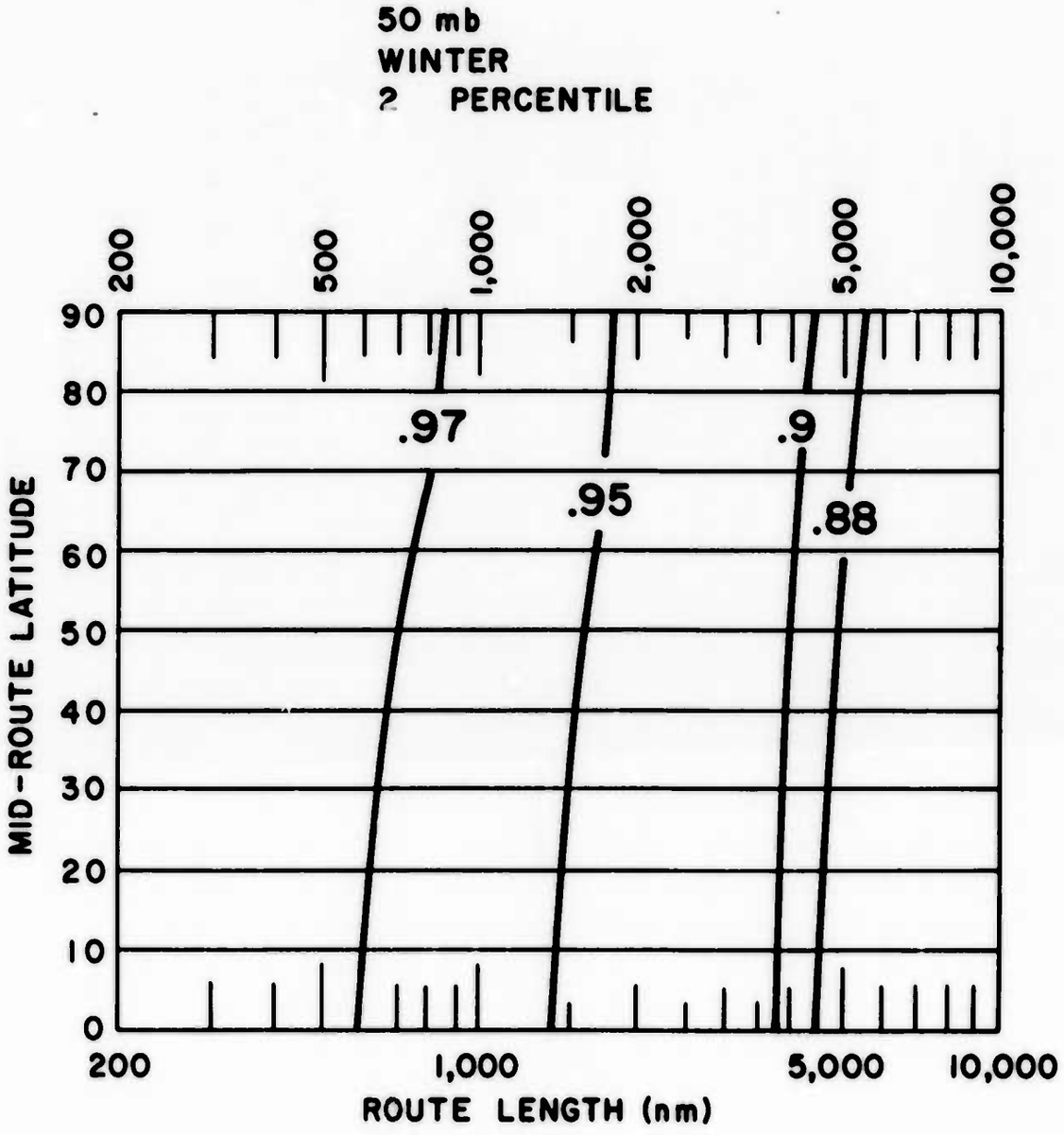


Plate 29. Temperature at 50 mb, in December, January, February, 2 Percentile



Graph 29. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

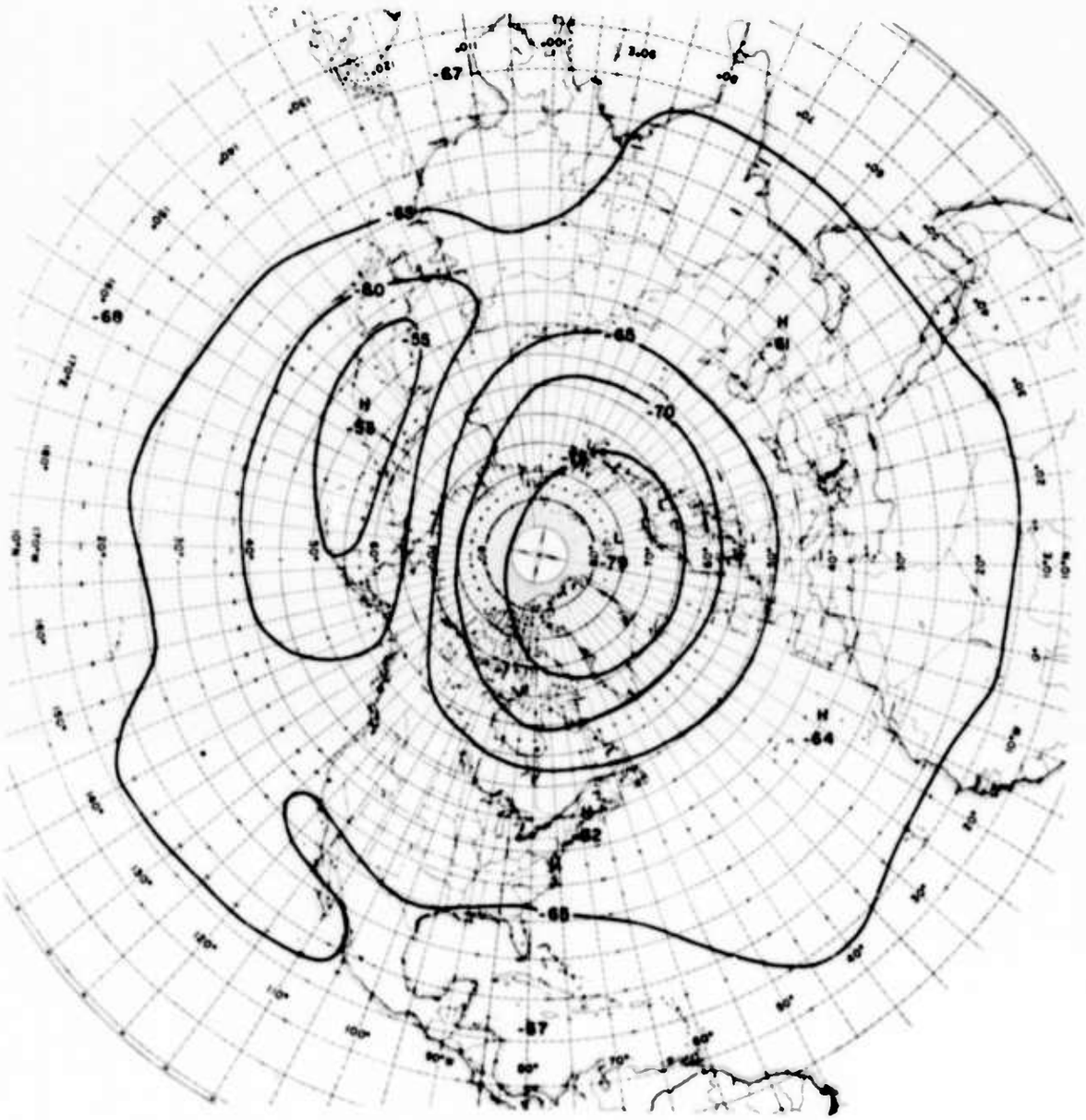
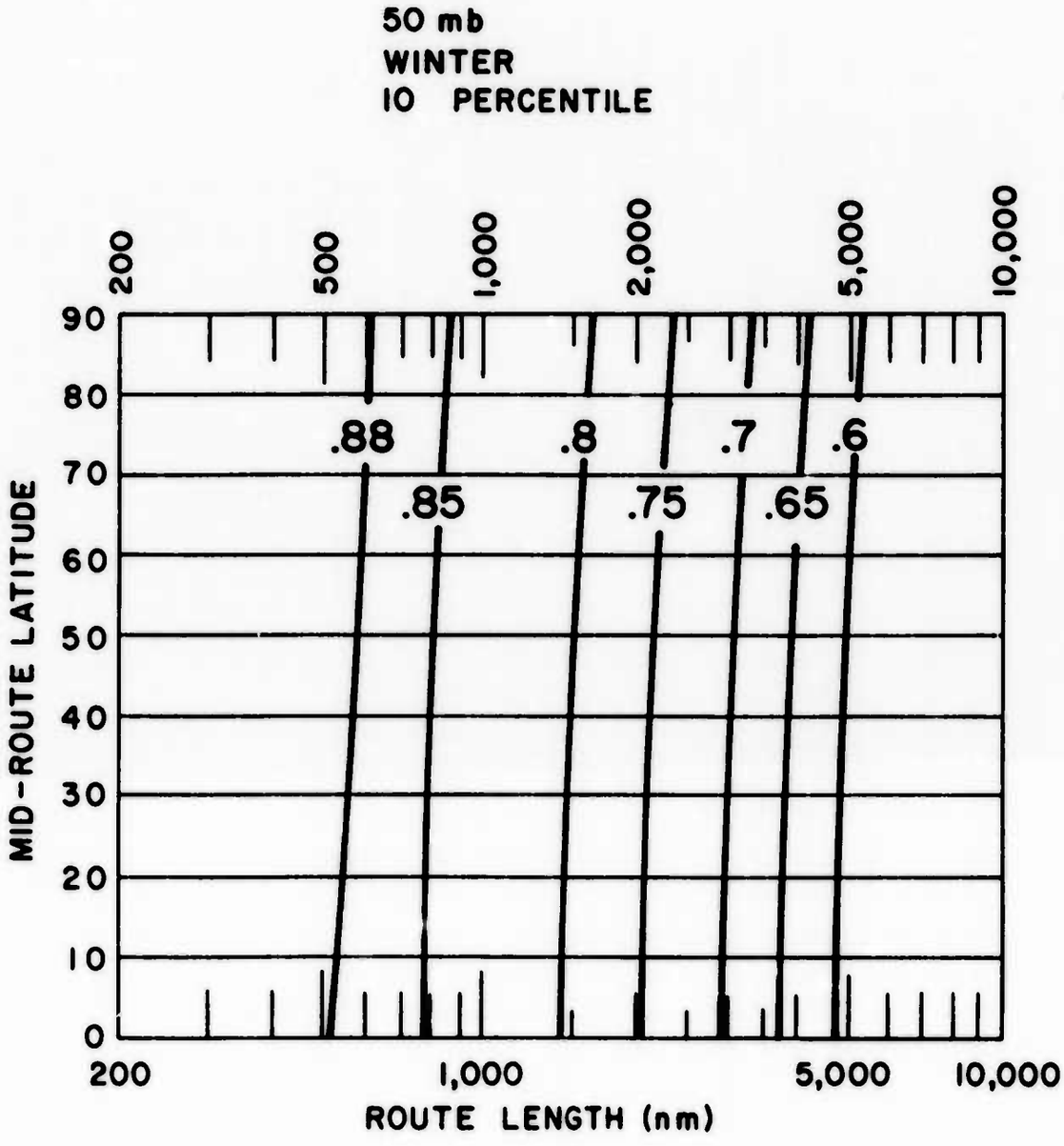


Plate 30. Temperature at 50 mb, in December, January, February, 10 Percentile



Graph 30. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

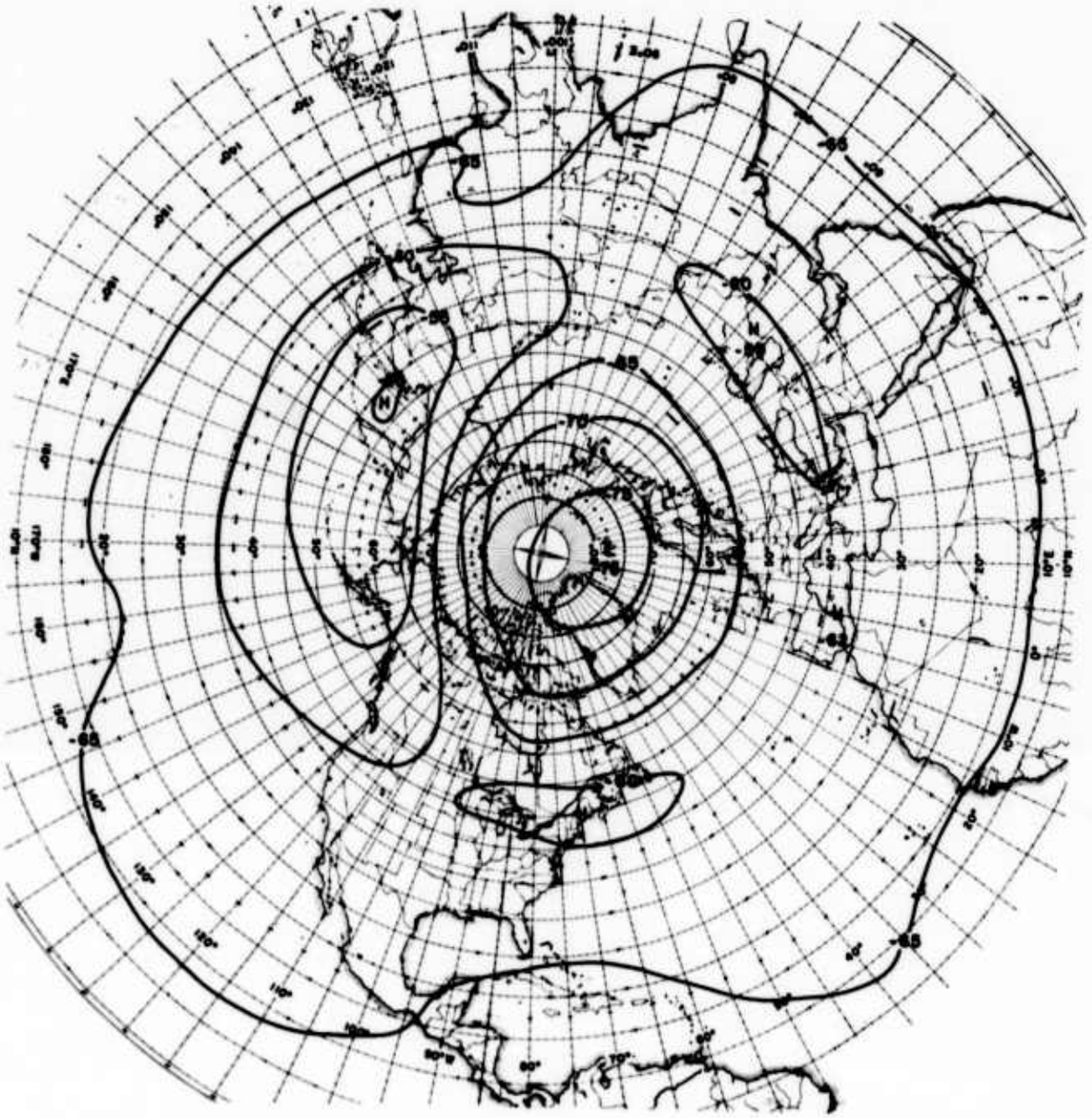
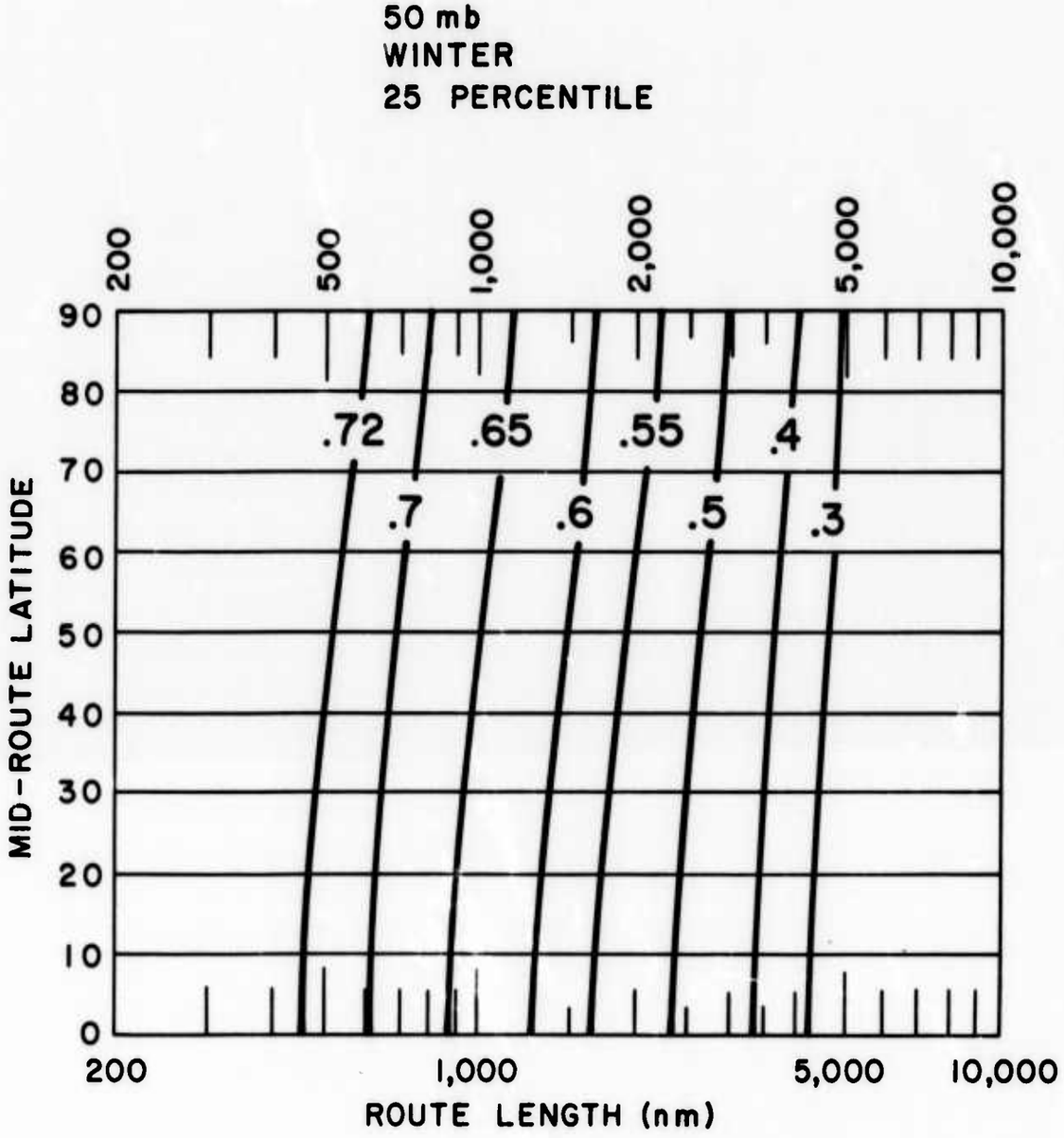


Plate 31. Temperature at 50 mb, in December, January, February, 25 Percentile



Graph 31. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

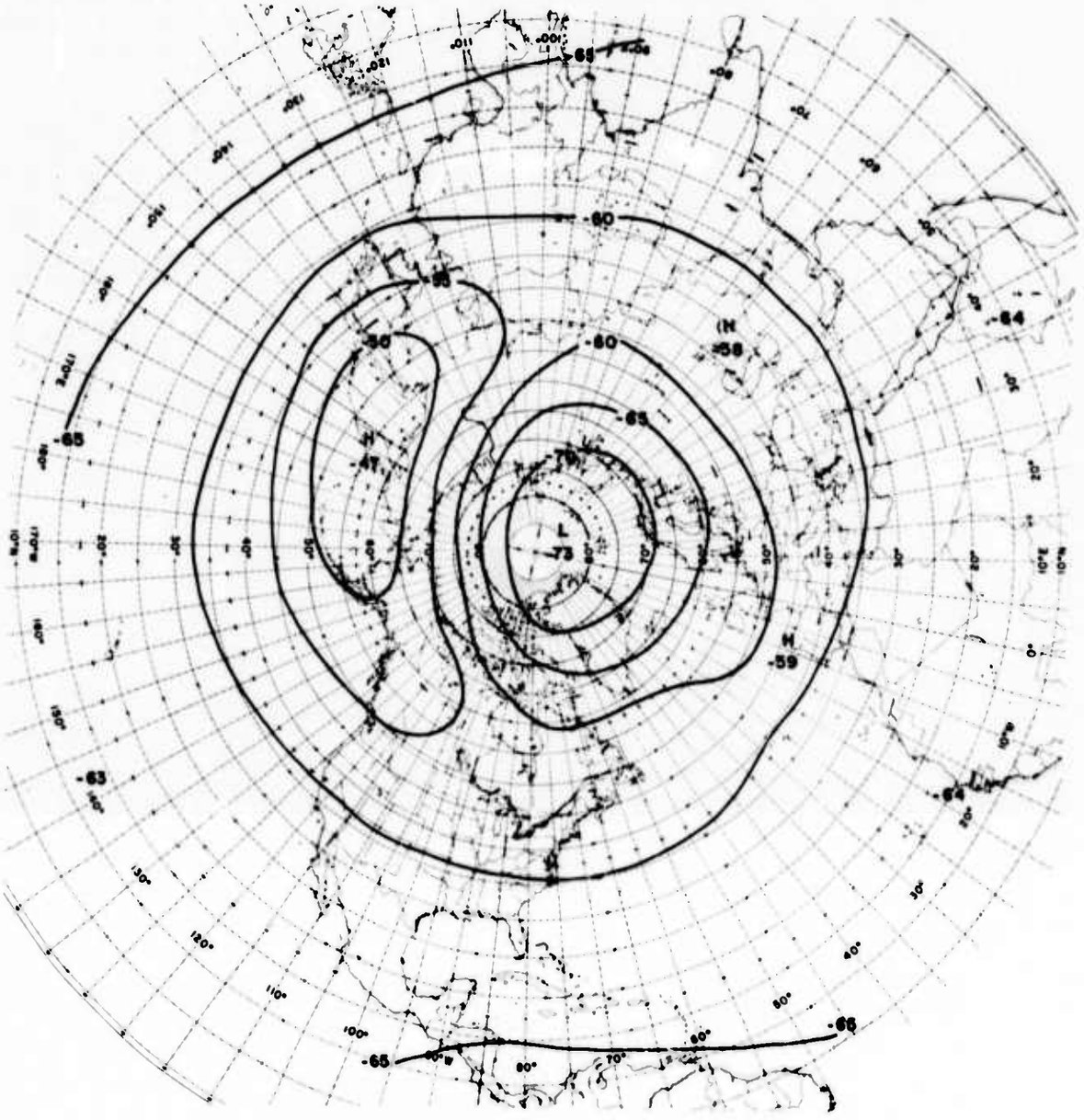
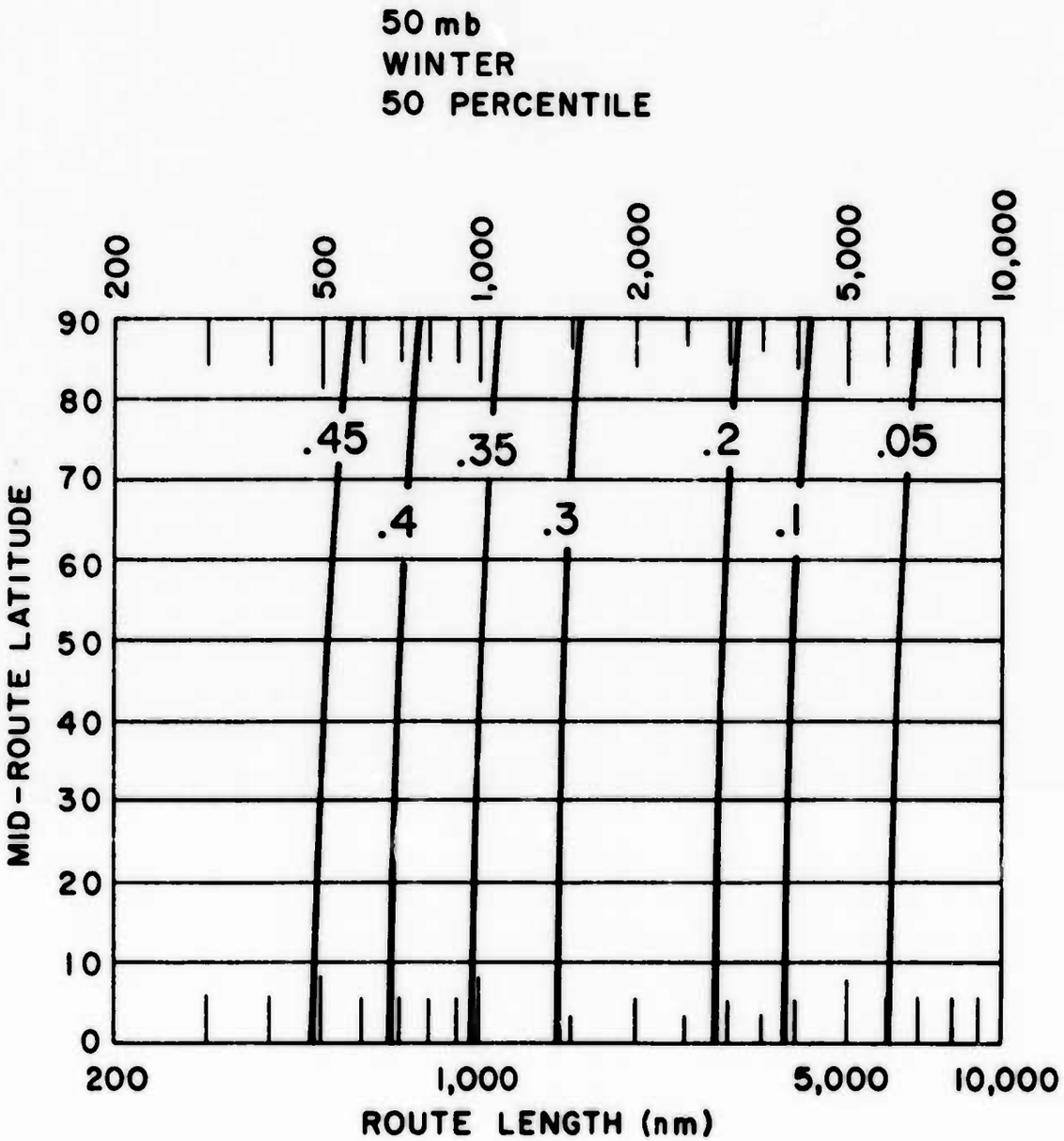


Plate 32. Temperature at 50 mb, in December, January, February, 50 Percentile



Graph 32. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

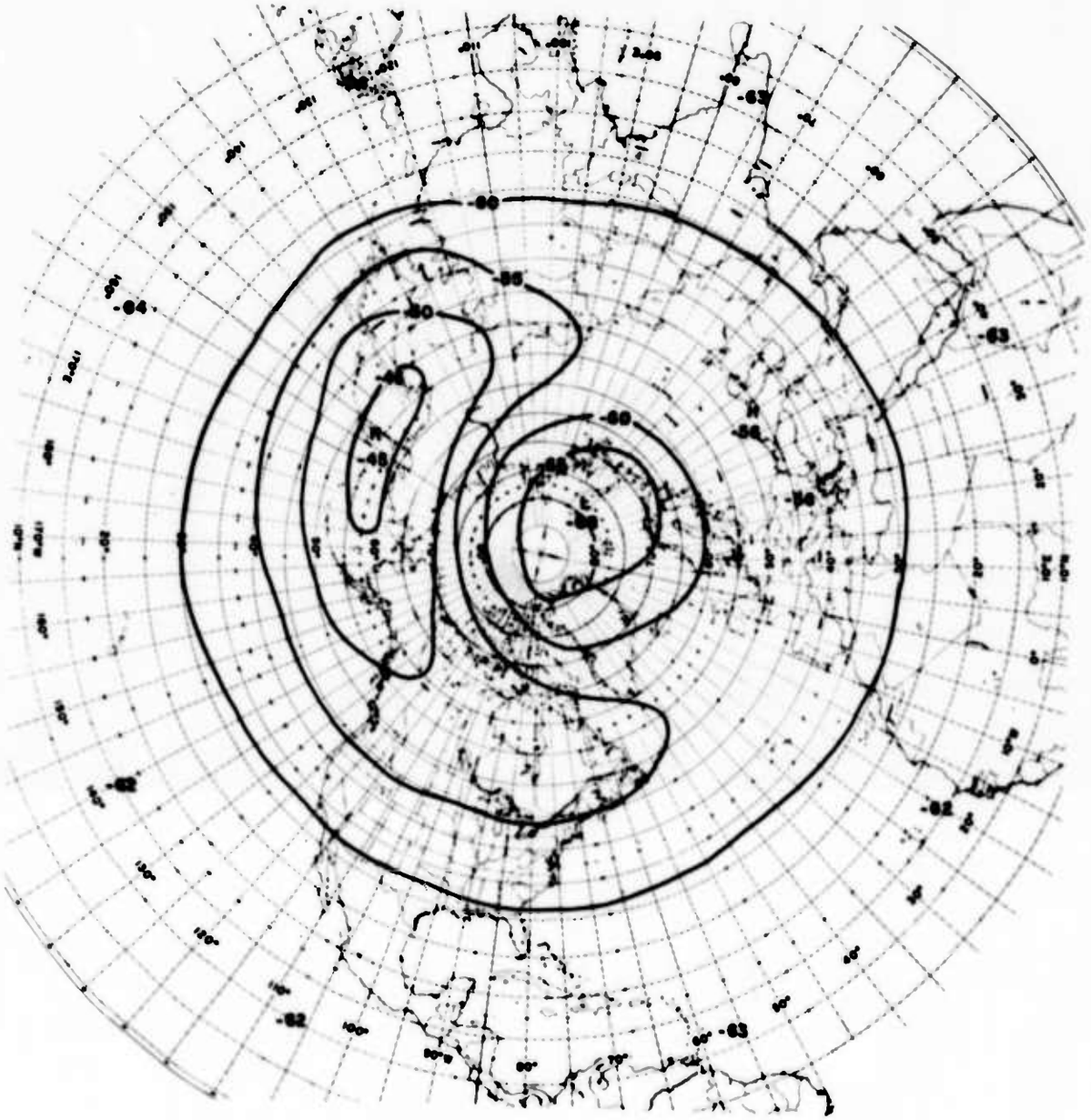
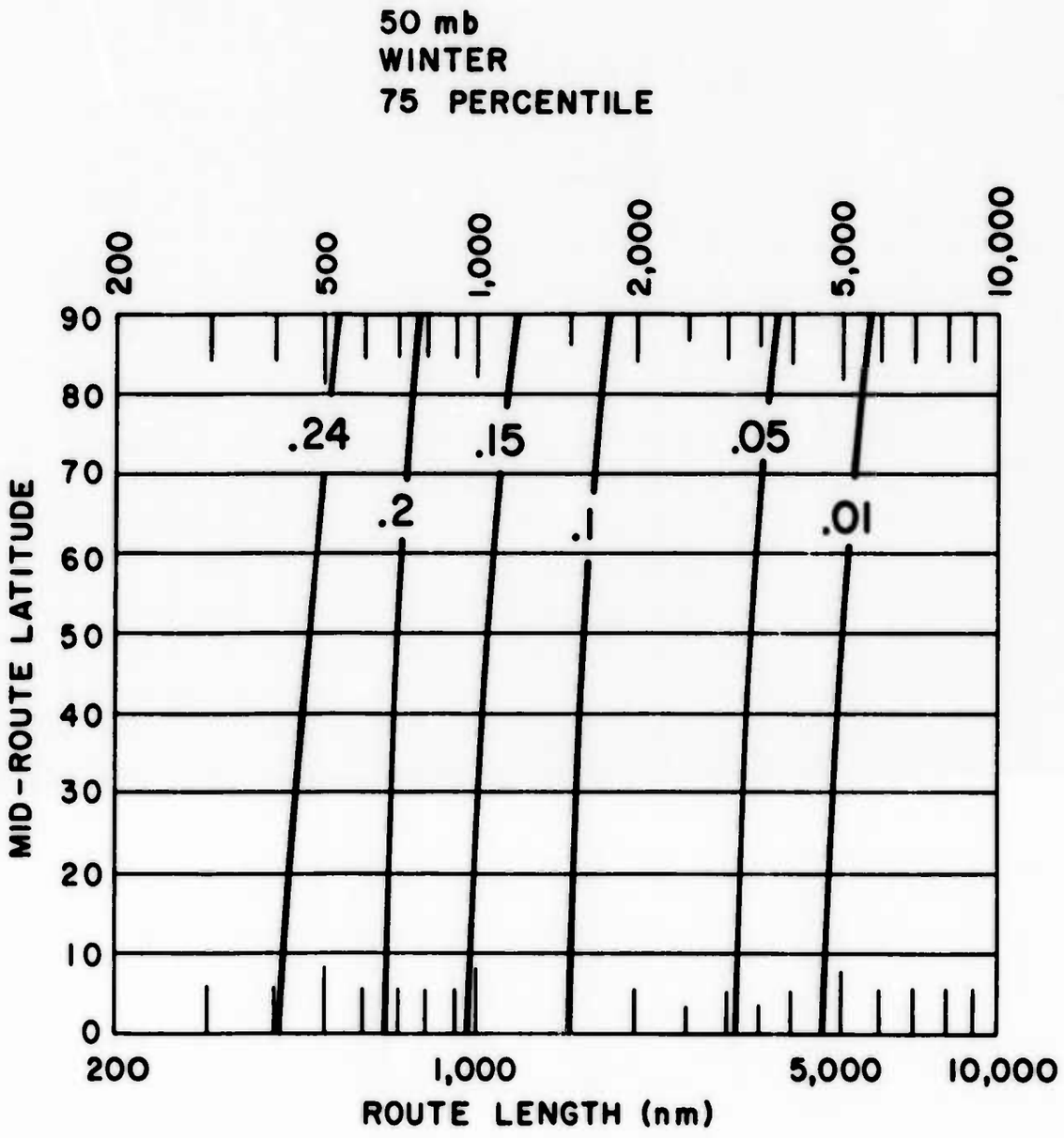
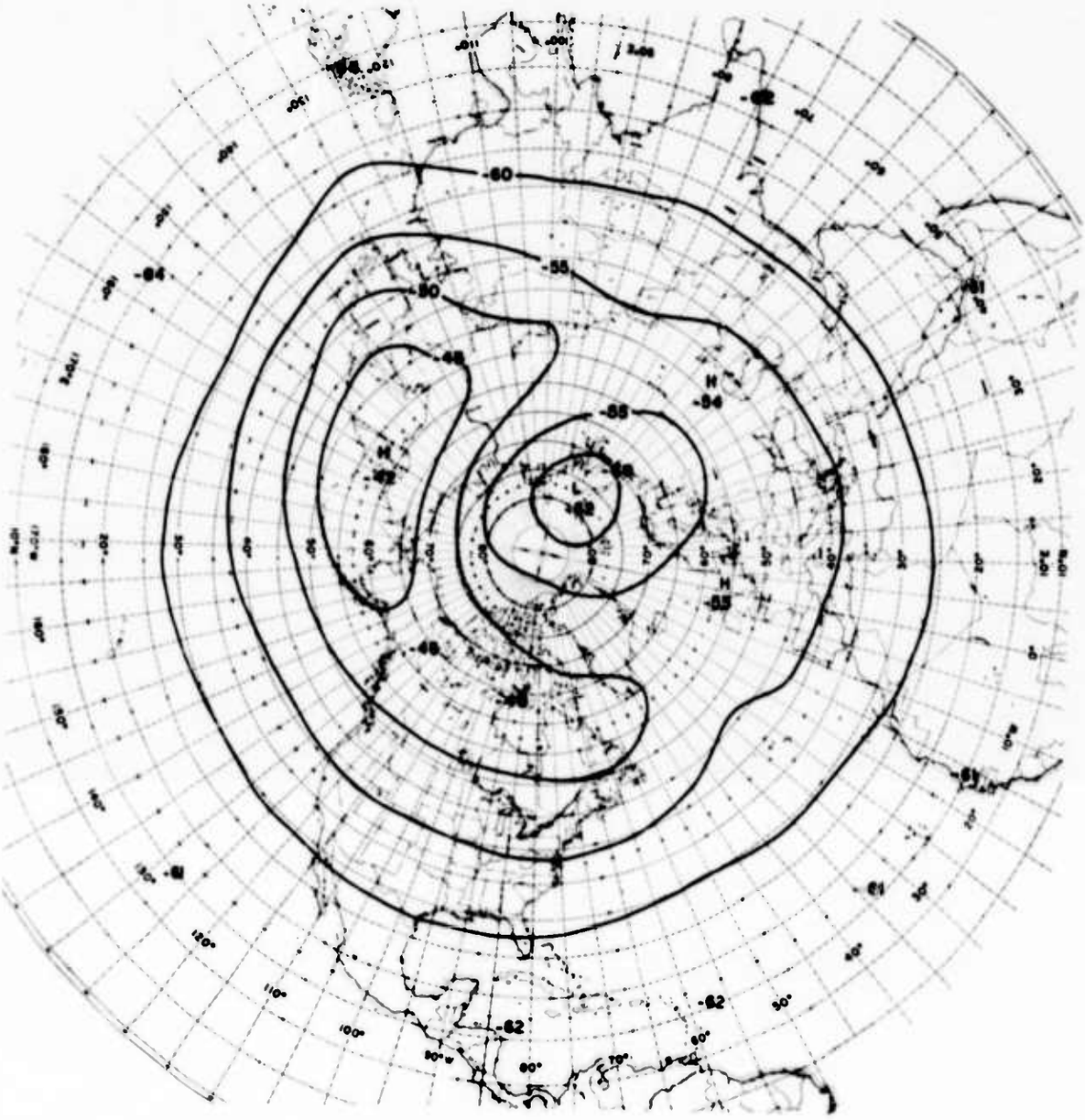


Plate 33. Temperature at 50 mb, in December, January, February, 75 Percentile



Graph 33. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page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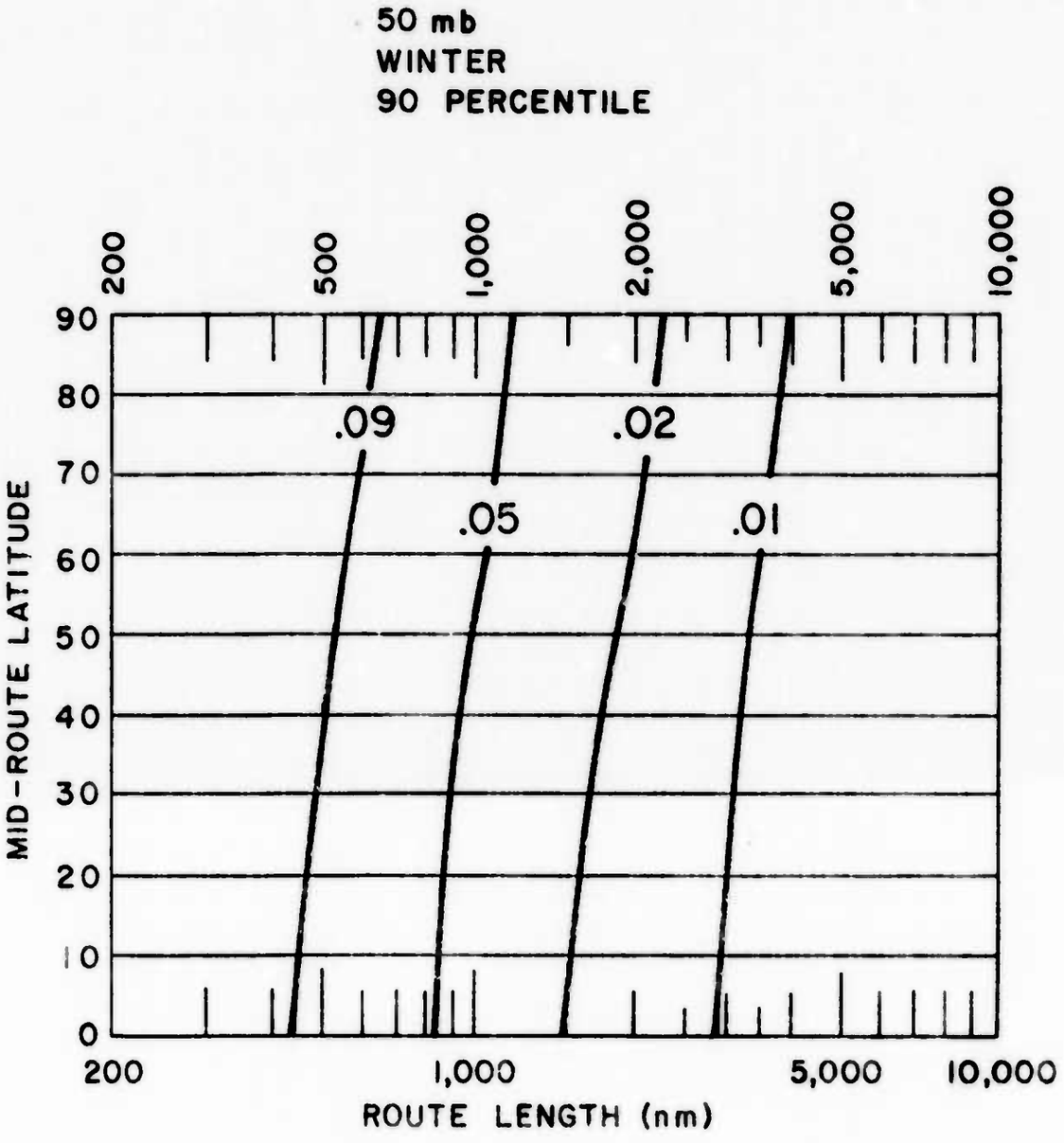


Graph 34. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

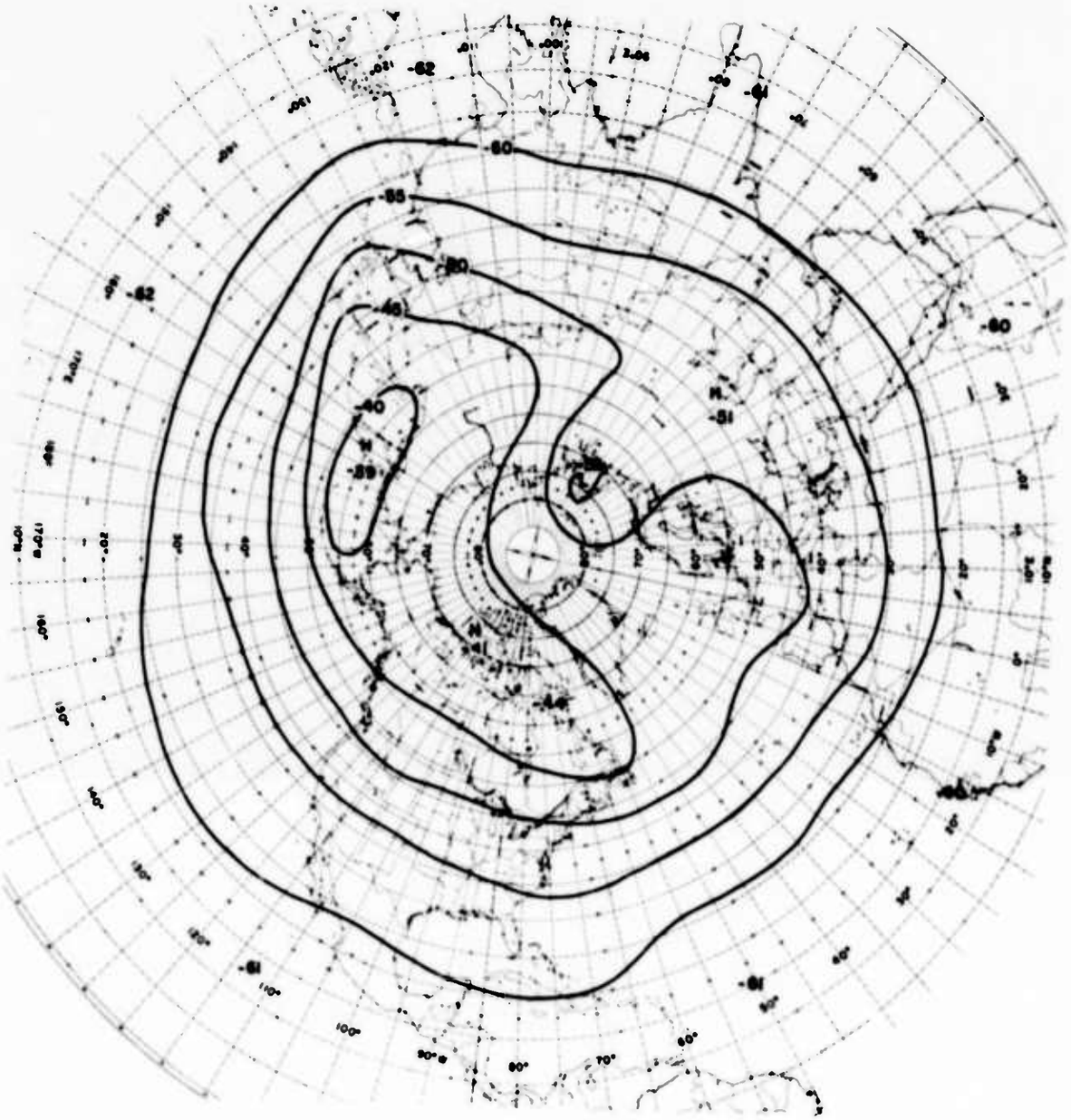
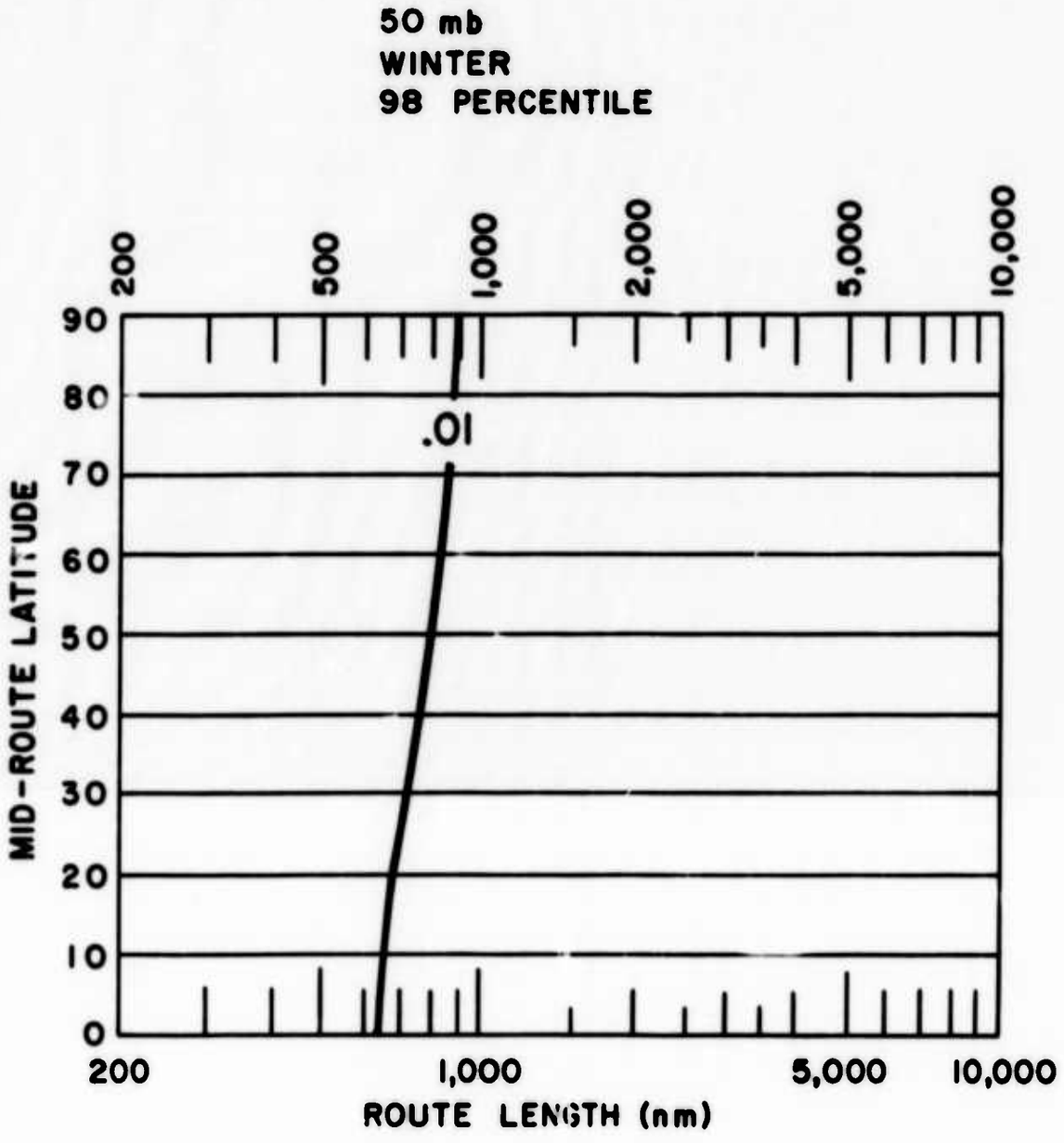


Plate 35. Temperature at 50 mb, in December, January, February, 98 Percentile



Graph 35. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

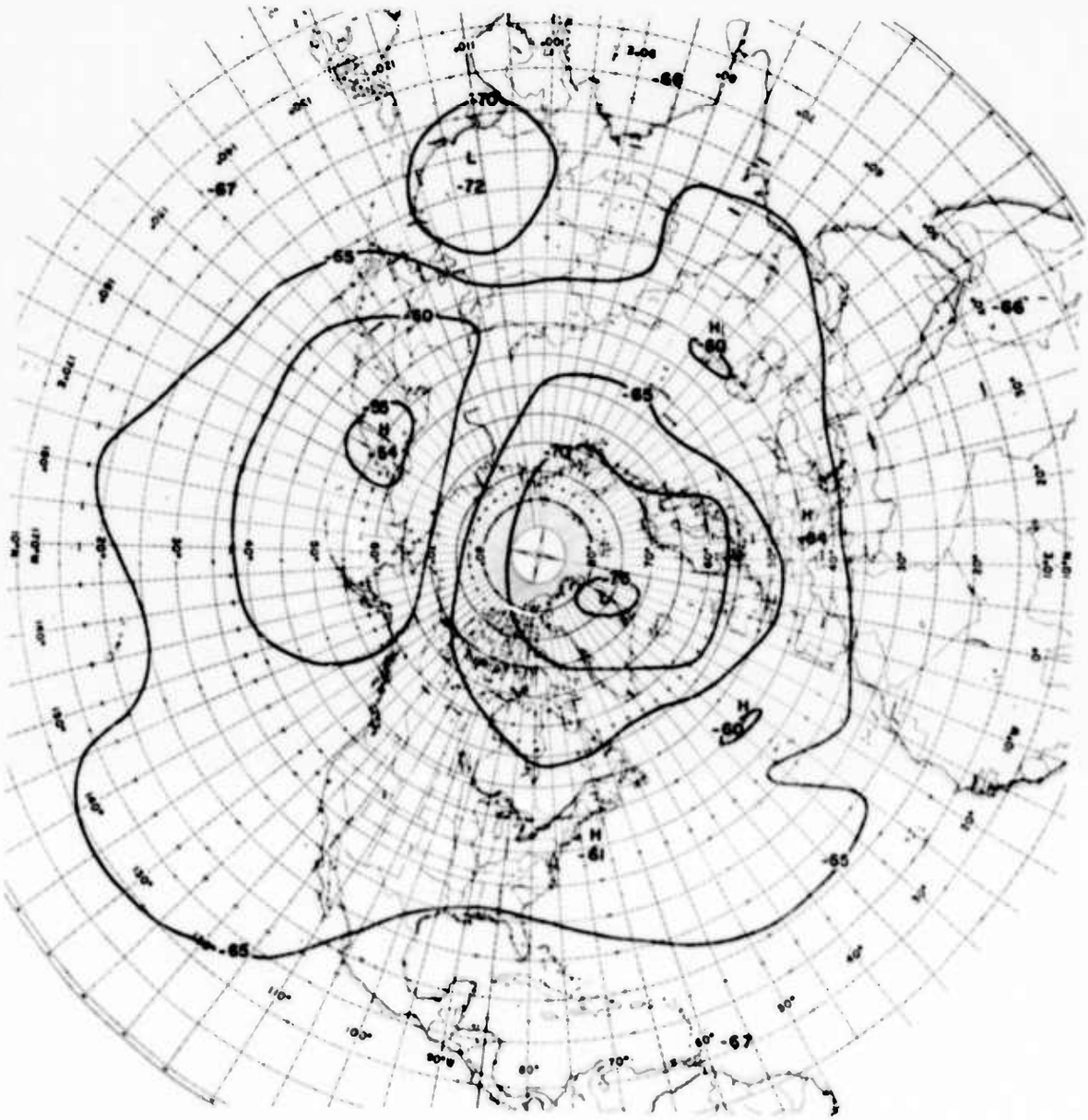
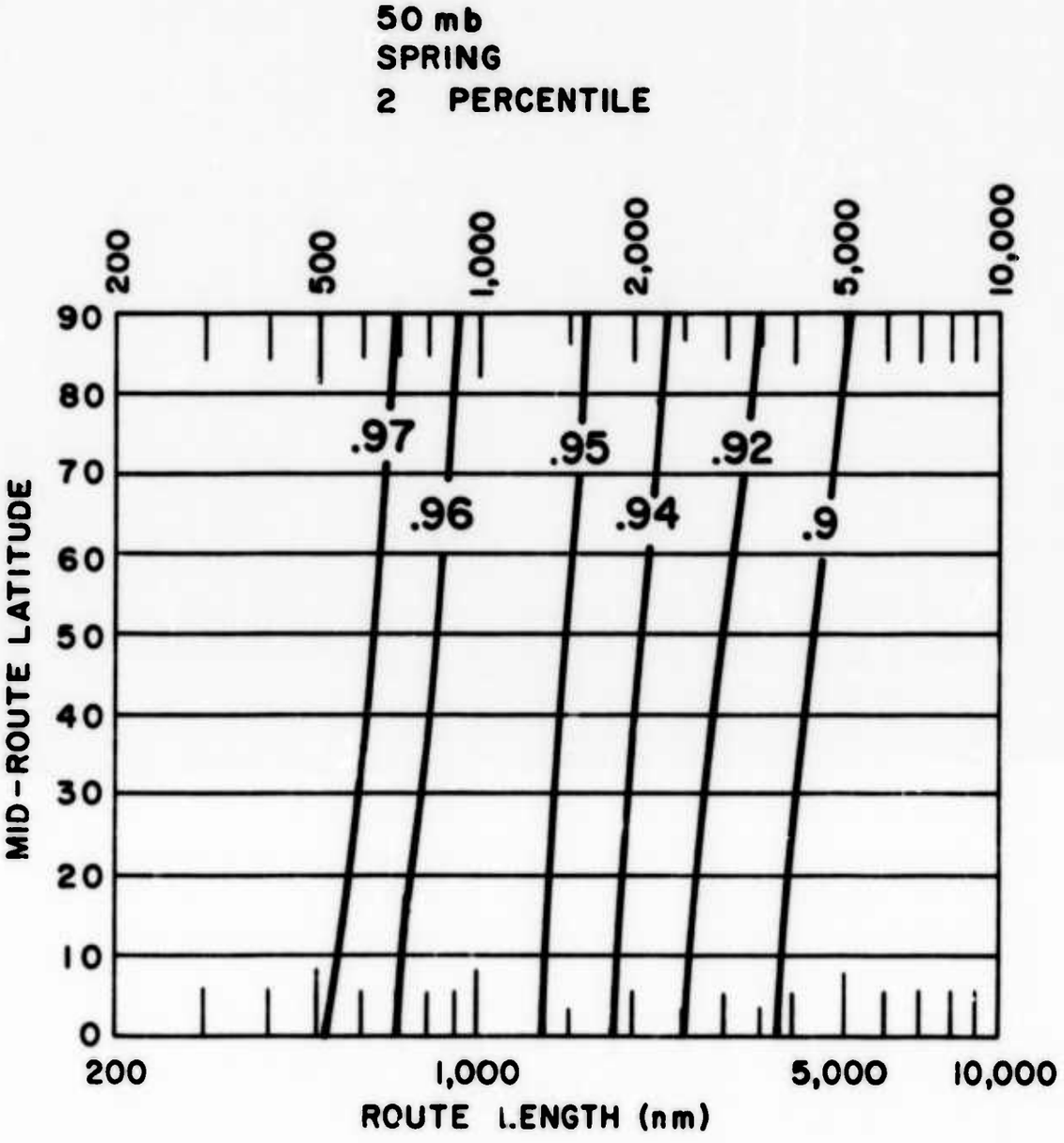


Plate 36. Temperature at 50 mb, in March, April, May, 2 Percentile



Graph 36. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

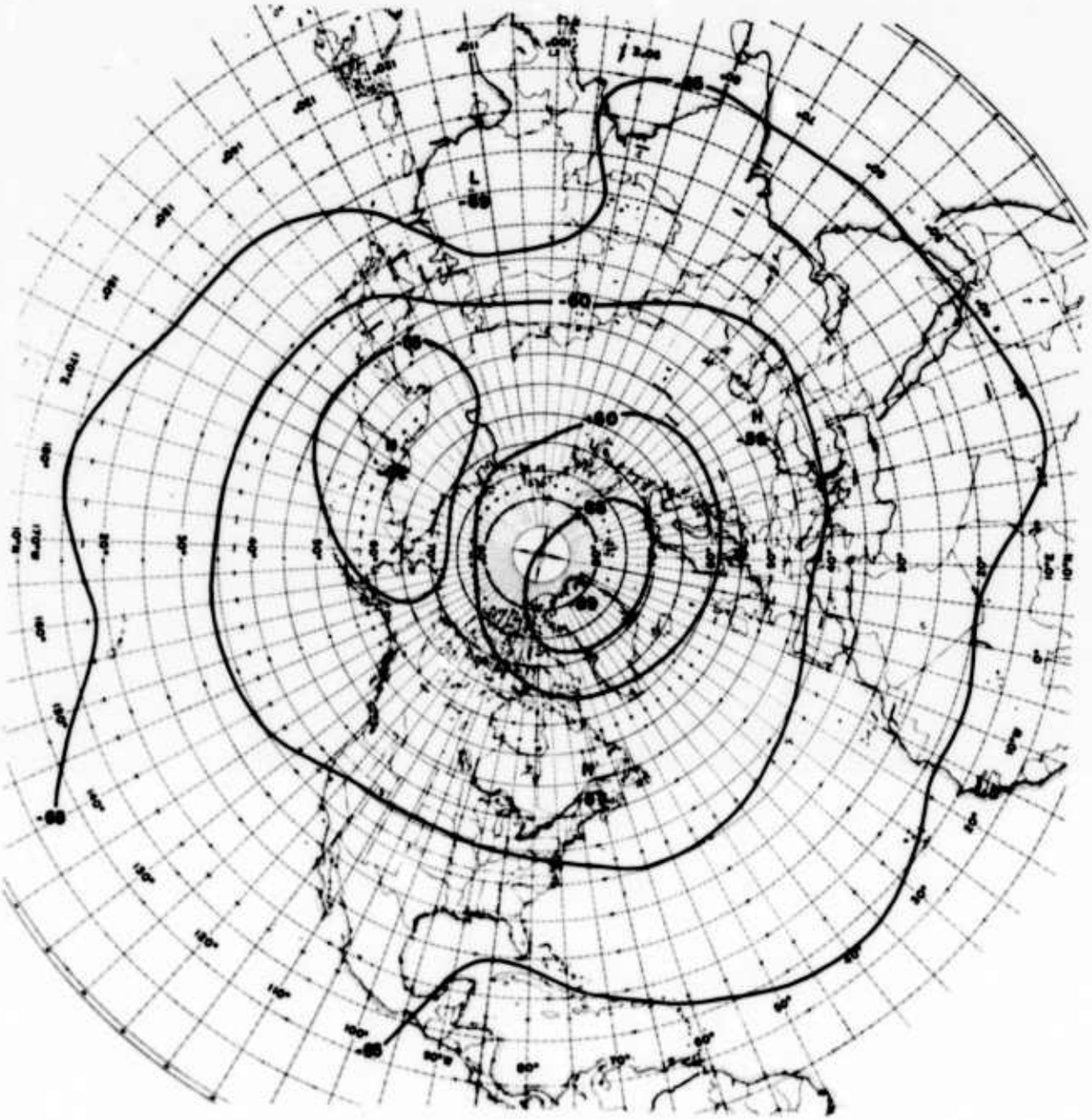
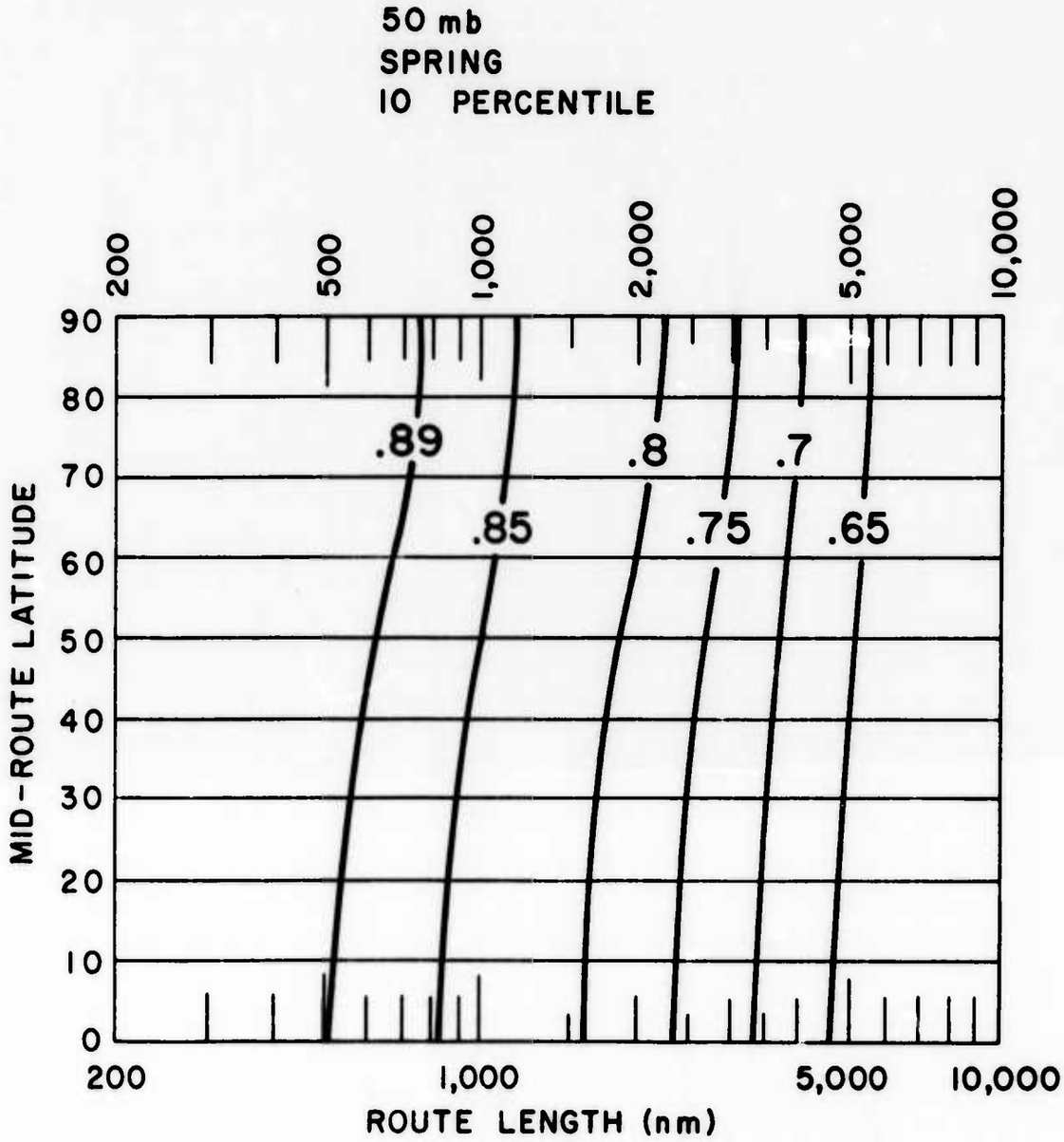


Plate 37. Temperature at 50 mb, in March, April, May, 10 Percentile



Graph 37. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

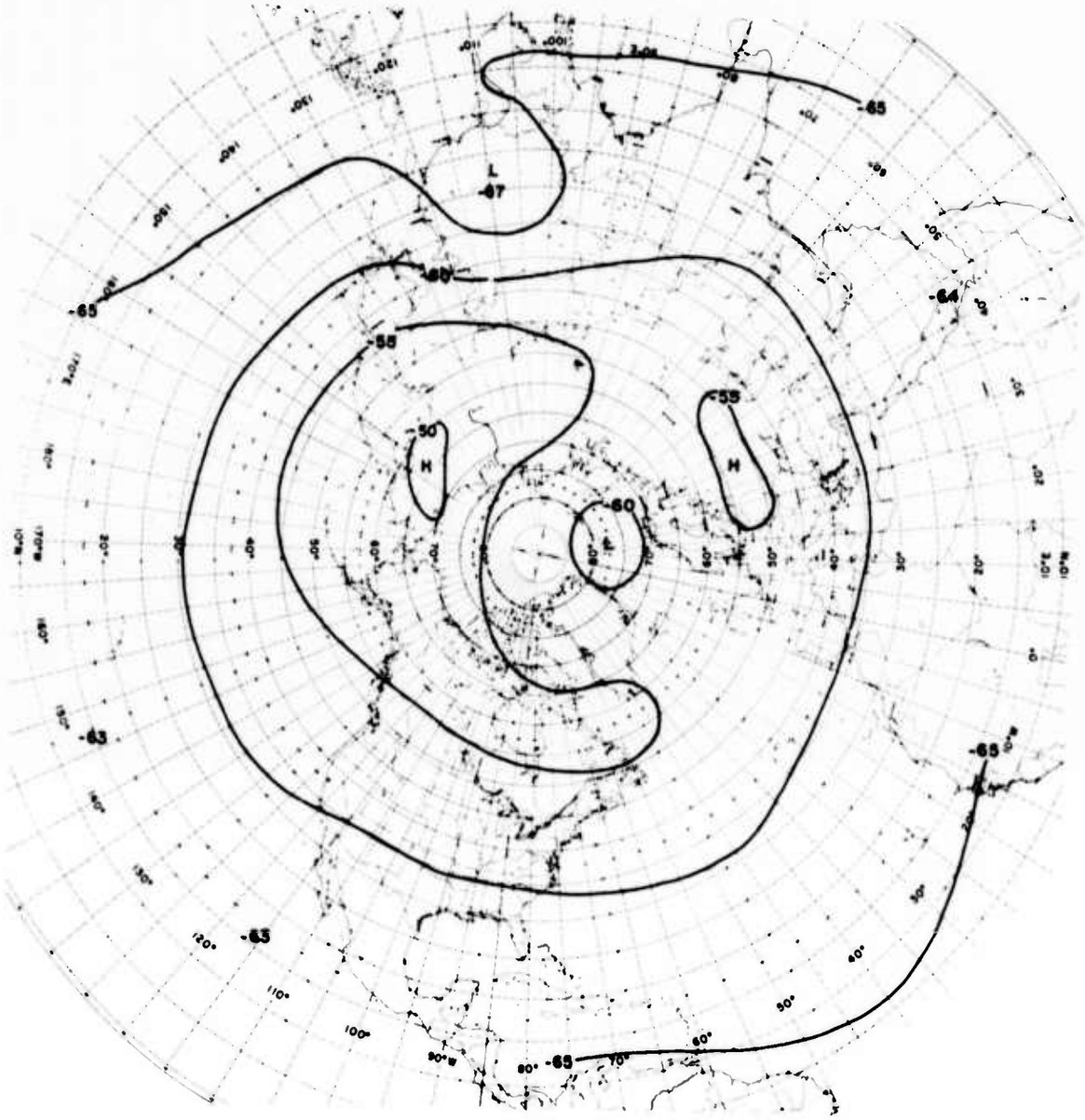
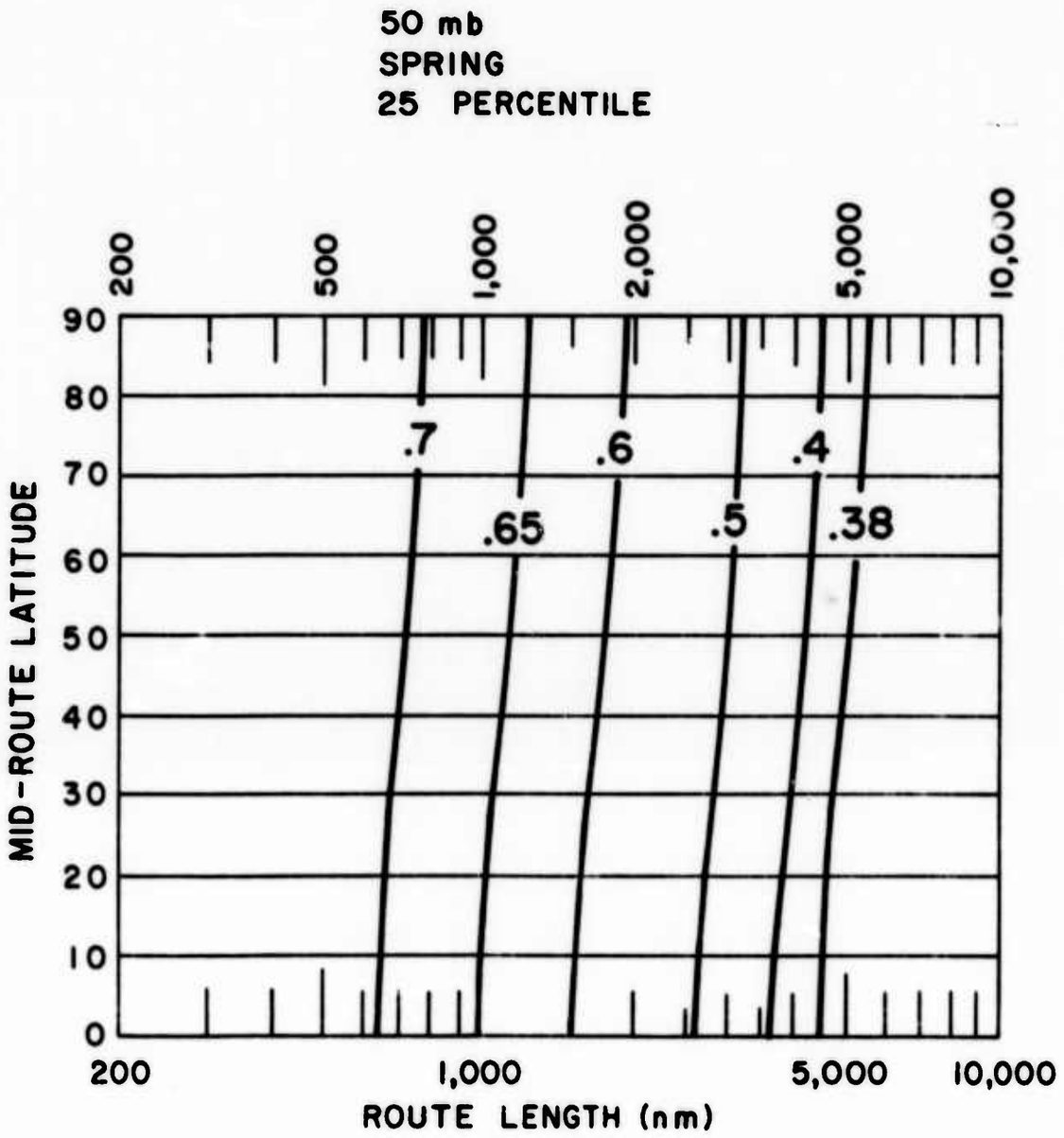


Plate 38. Temperature at 50 mb, in March, April, May, 25 Percentile



Graph 38. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

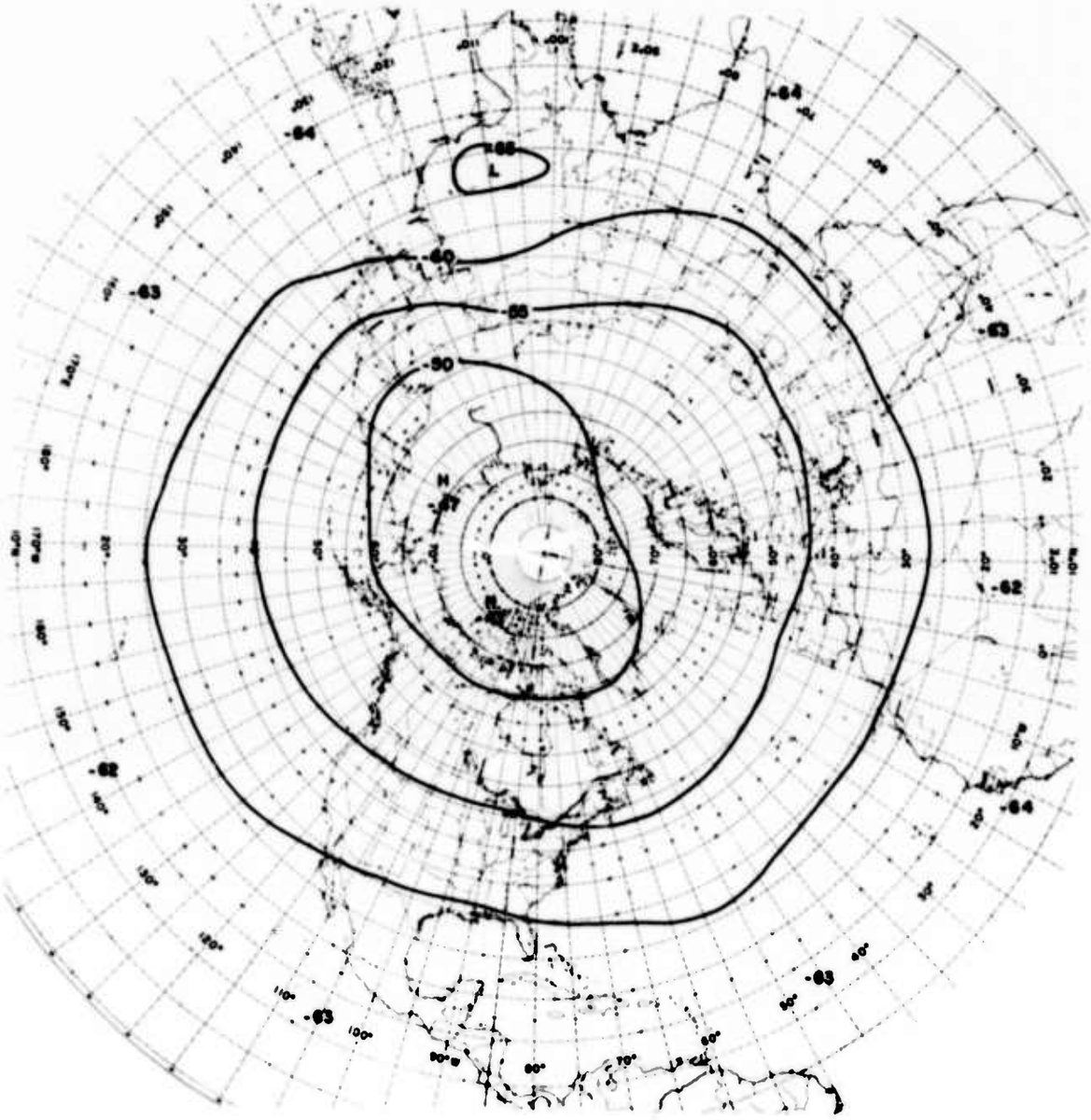
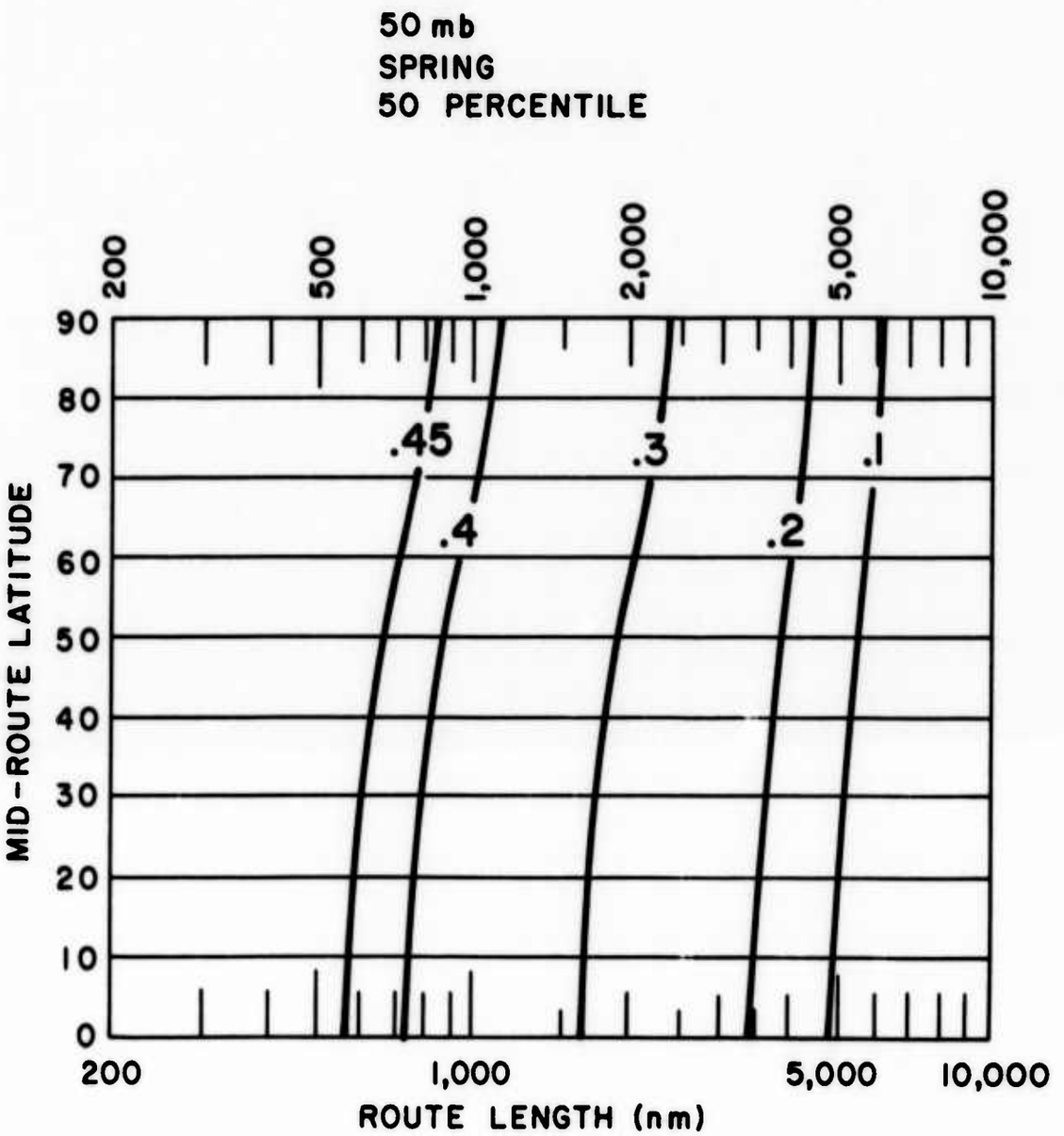


Plate 39. Temperature at 50 mb, in March, April, May, 50 Percentile



Graph 39. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

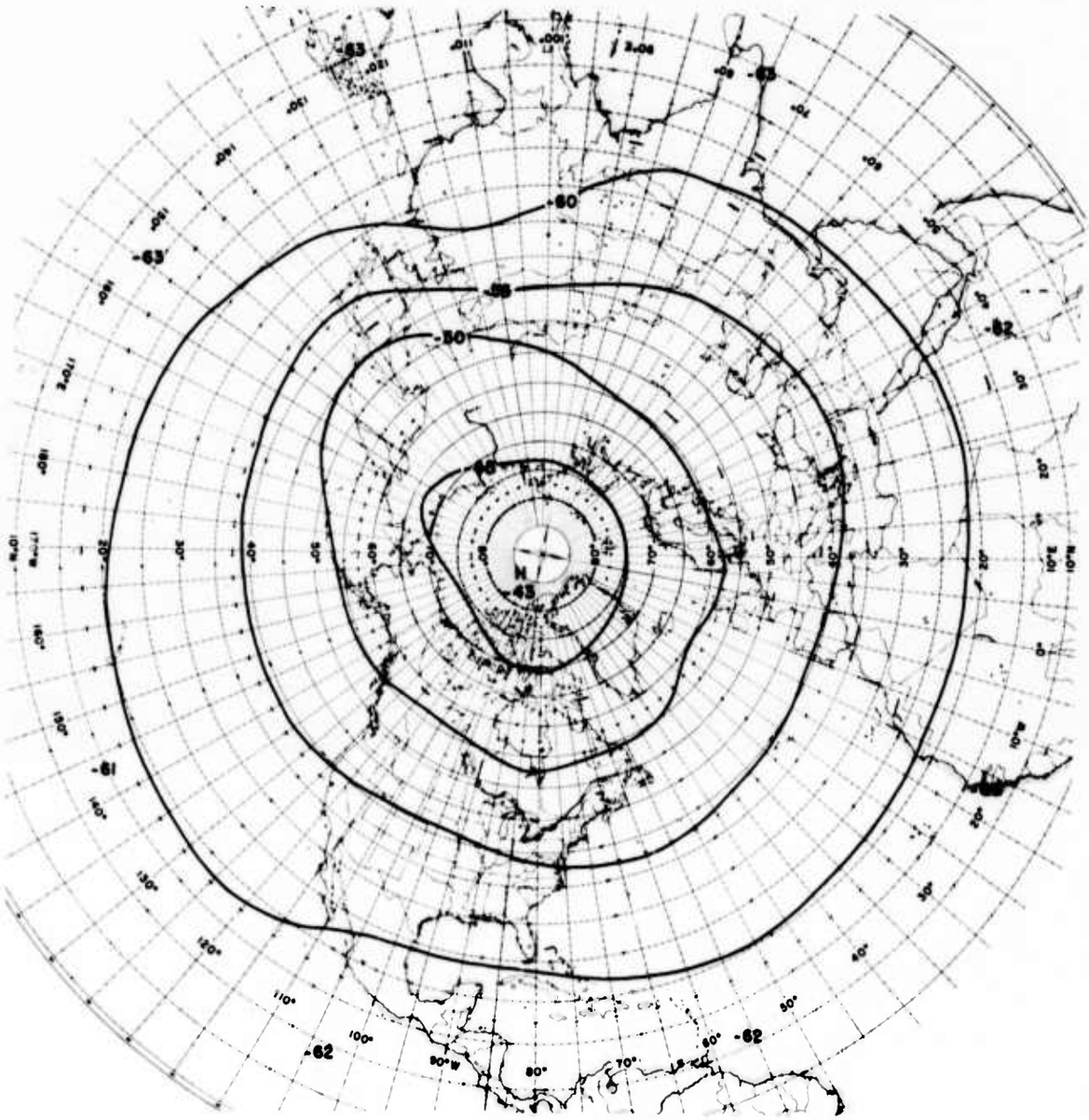
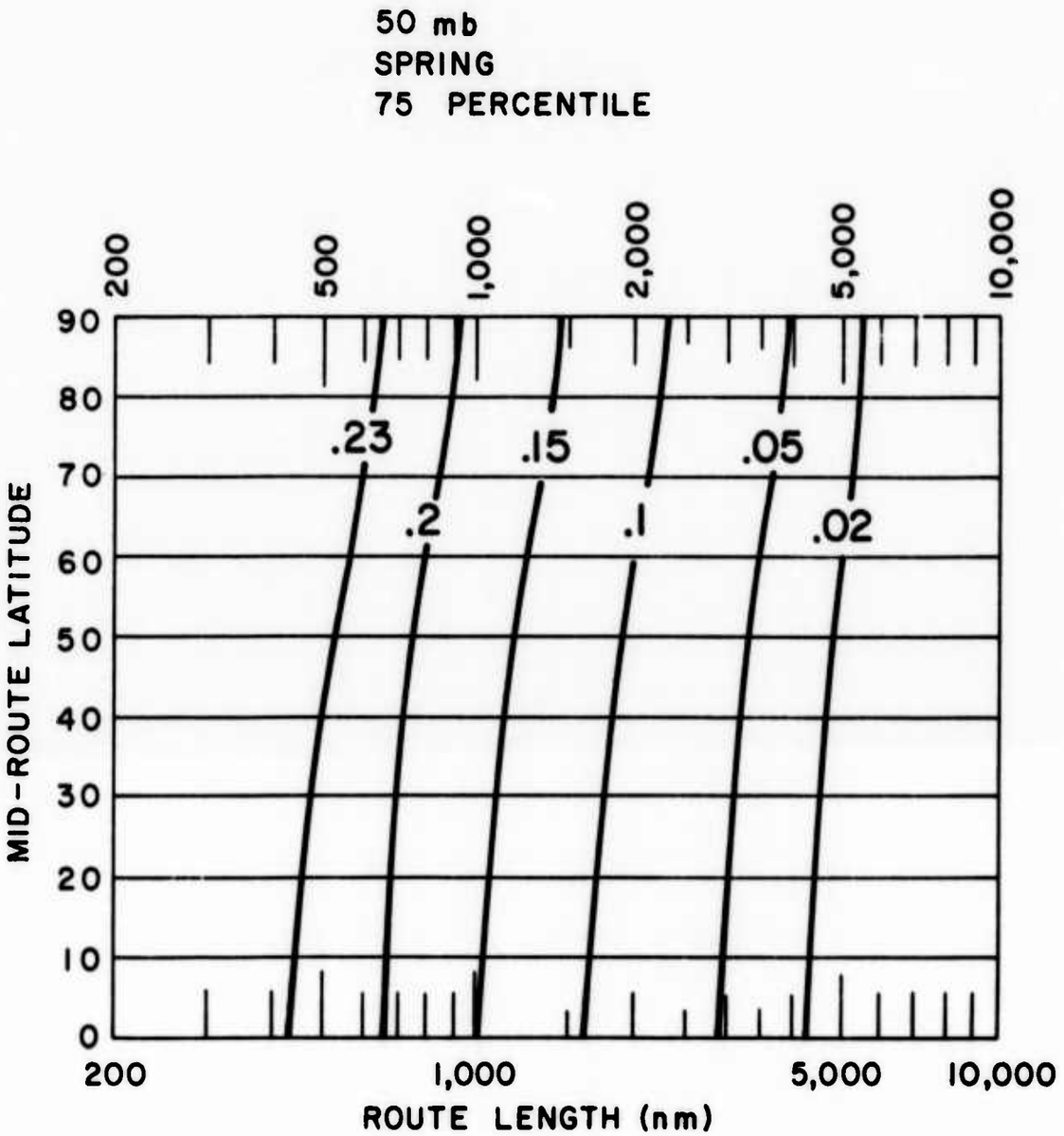


Plate 40. Temperature at 50 mb, in March, April, May, 75 Percentile



Graph 40. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

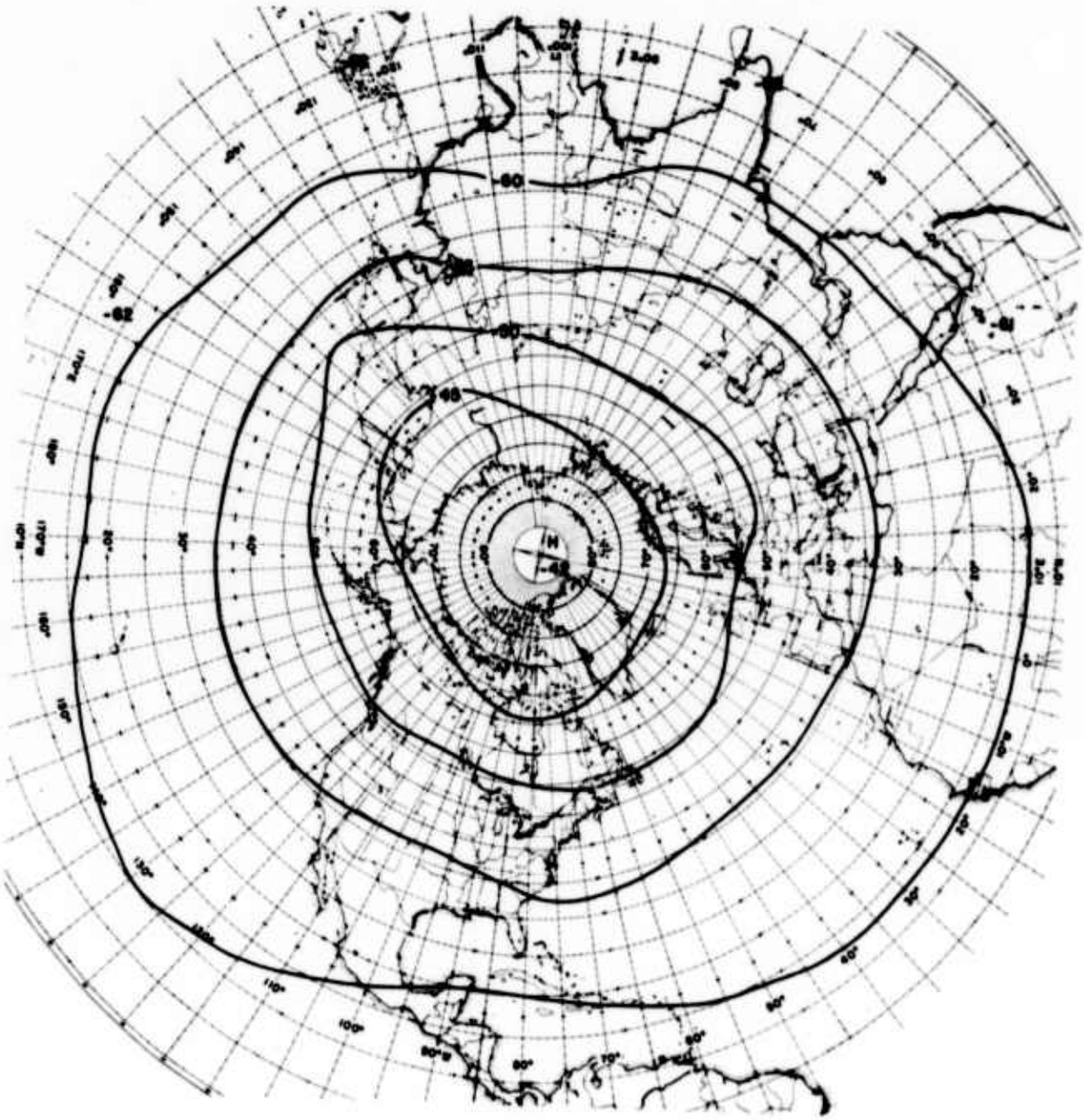
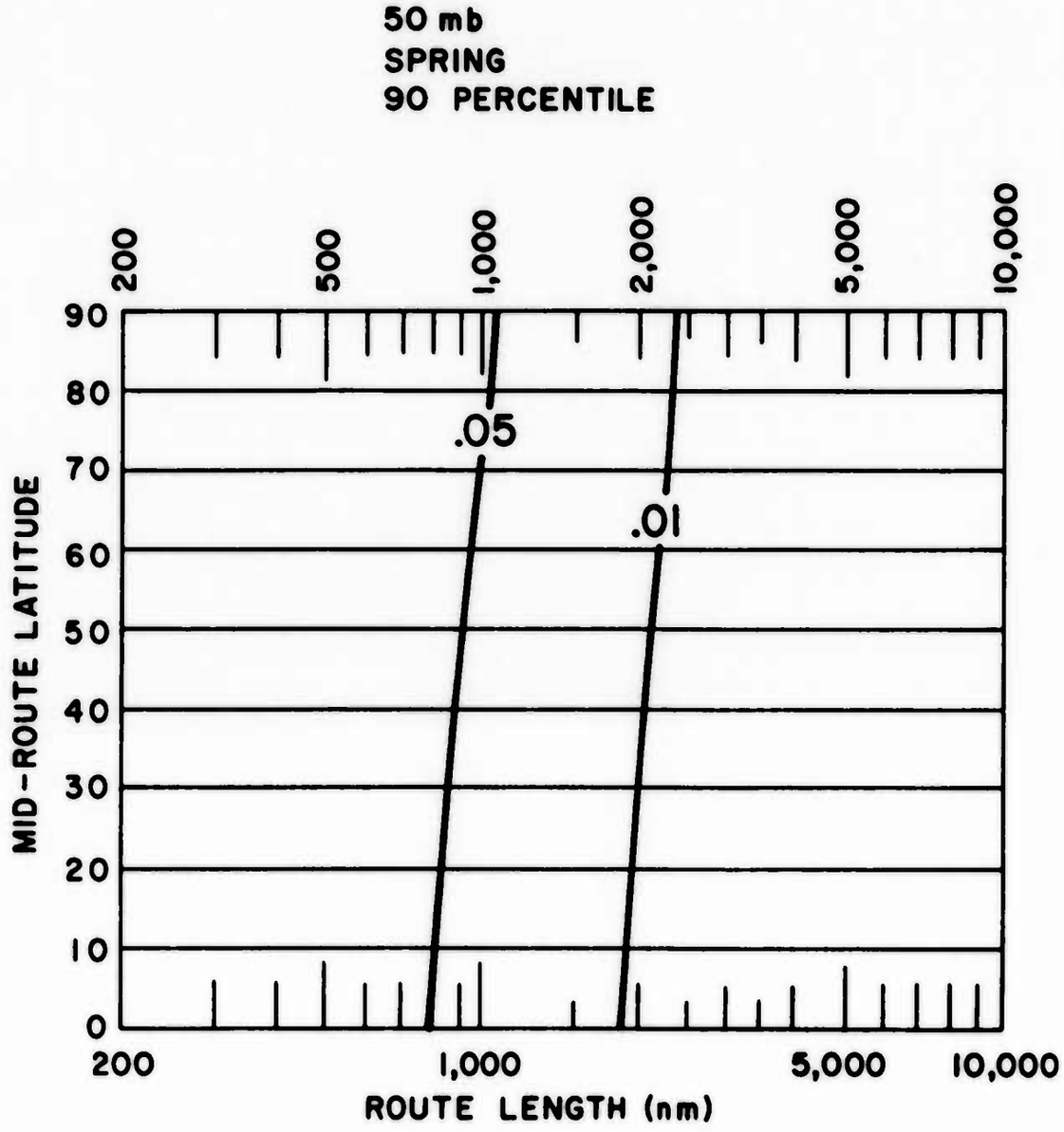


Plate 41. Temperature at 50 mb, in March, April, May, 90 Percentile



Graph 41. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

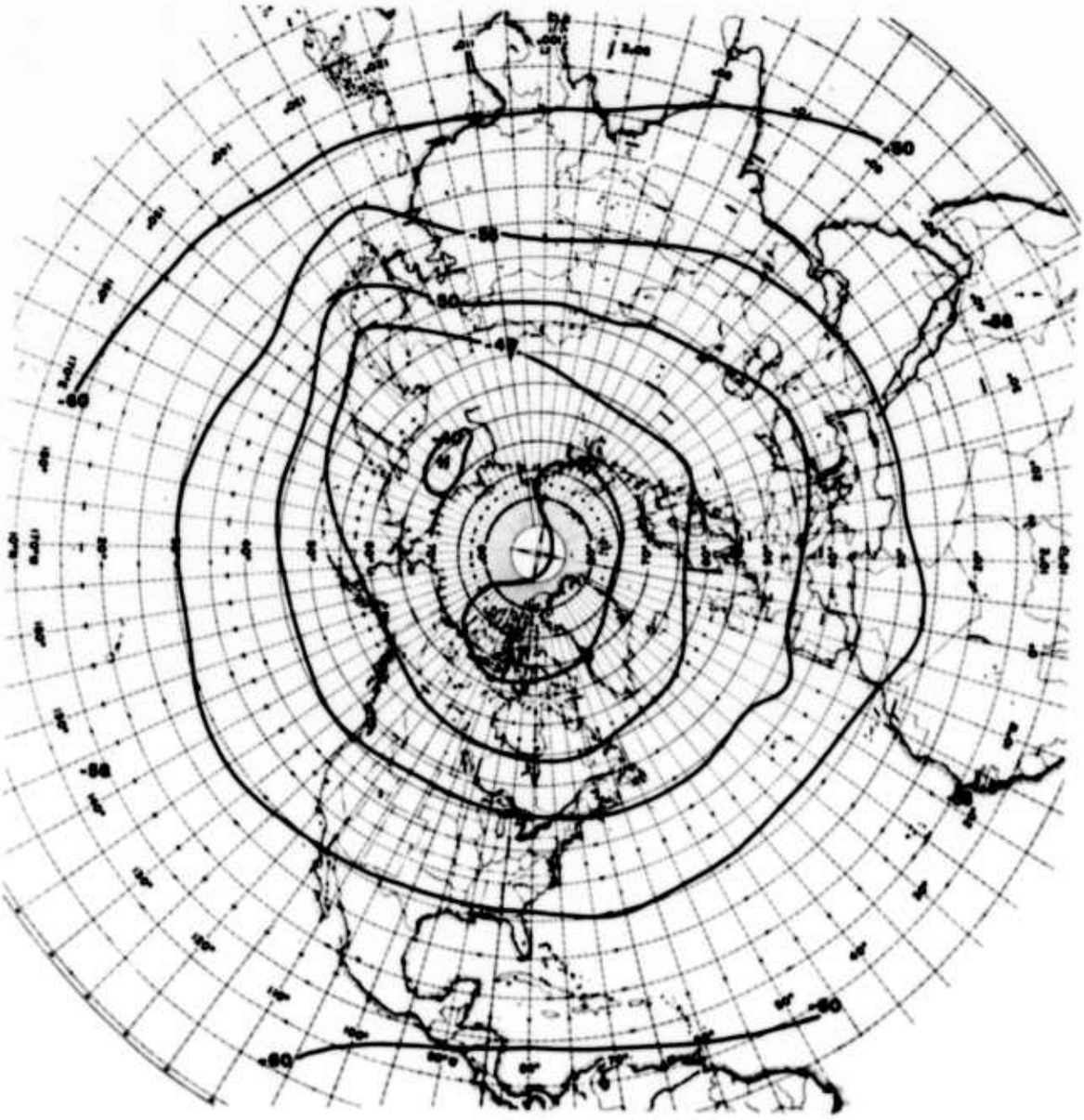
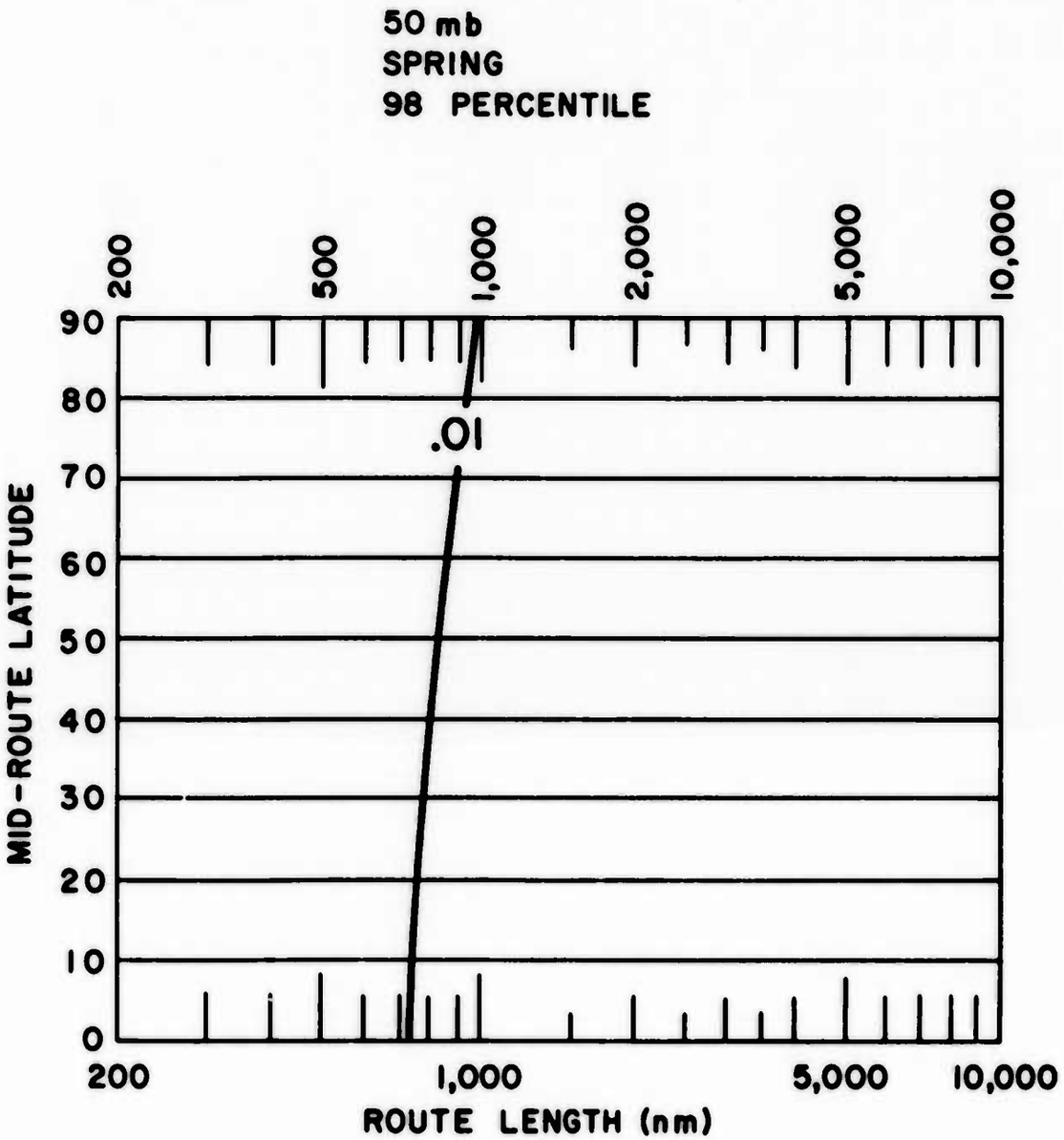


Plate 42. Temperature at 50 mb, in March, April, May, 98 Percentile



Graph 42. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

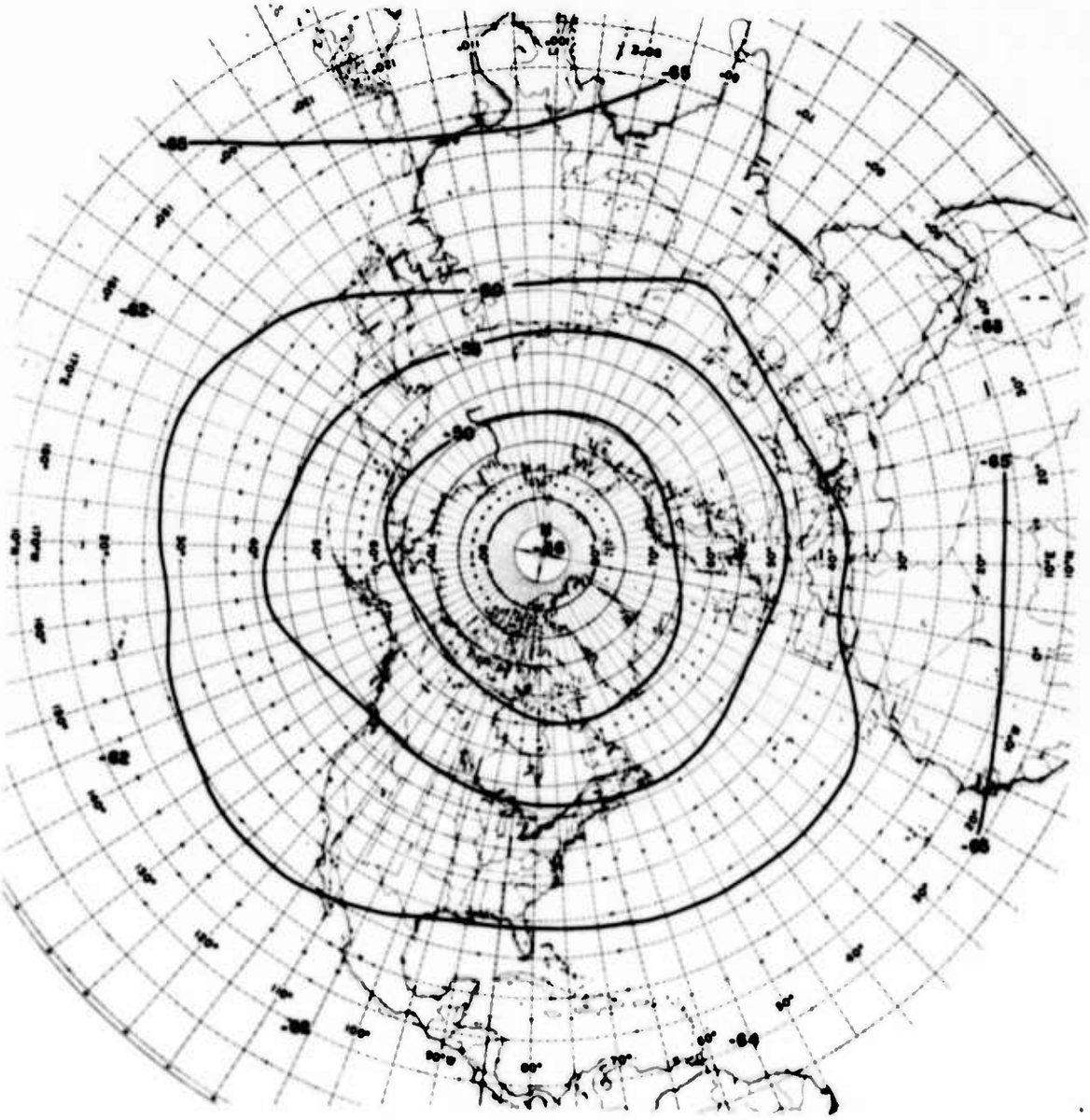
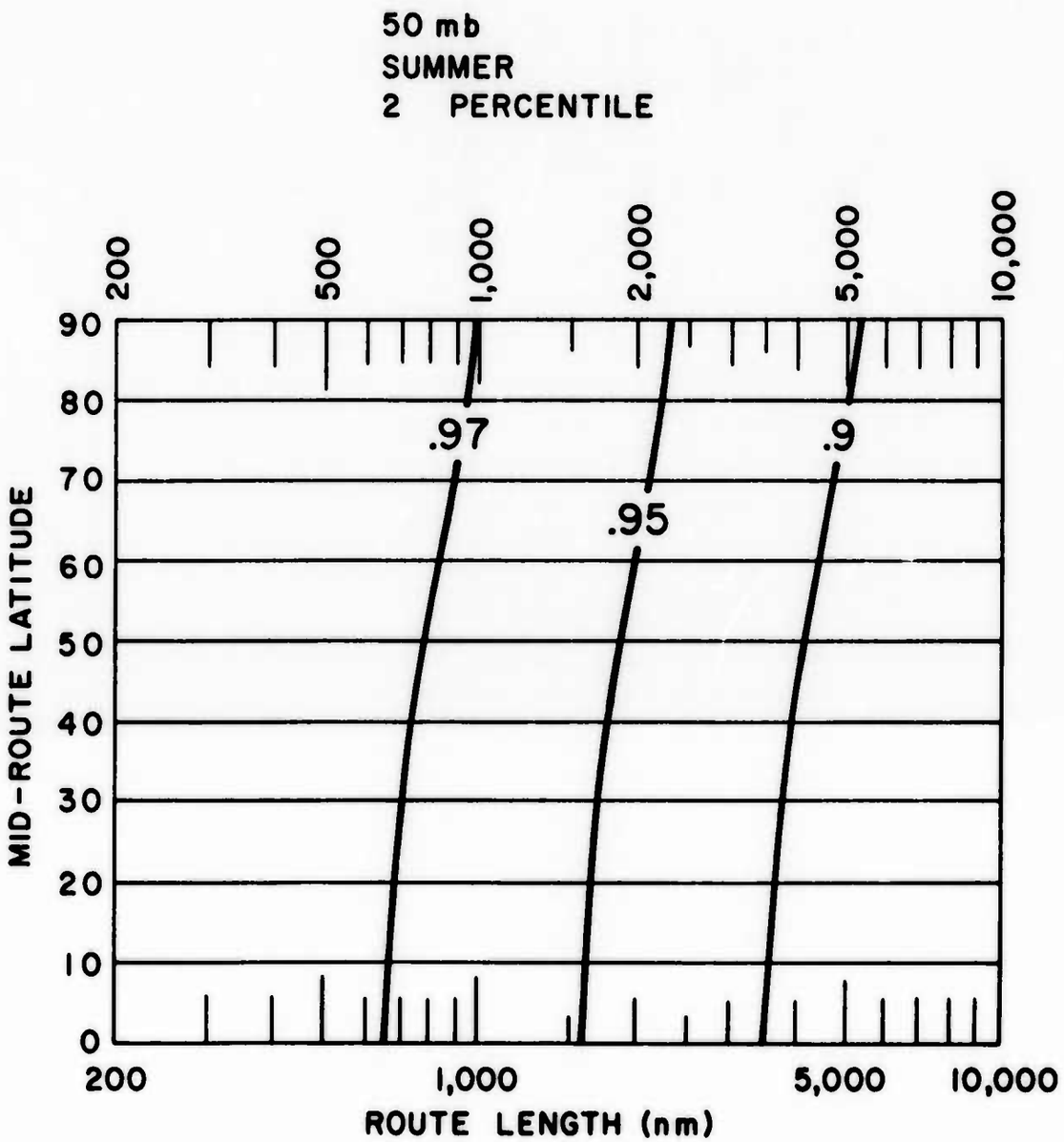


Plate 43. Temperature at 50 mb, in June, July, August, 2 Percentile



Graph 43. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

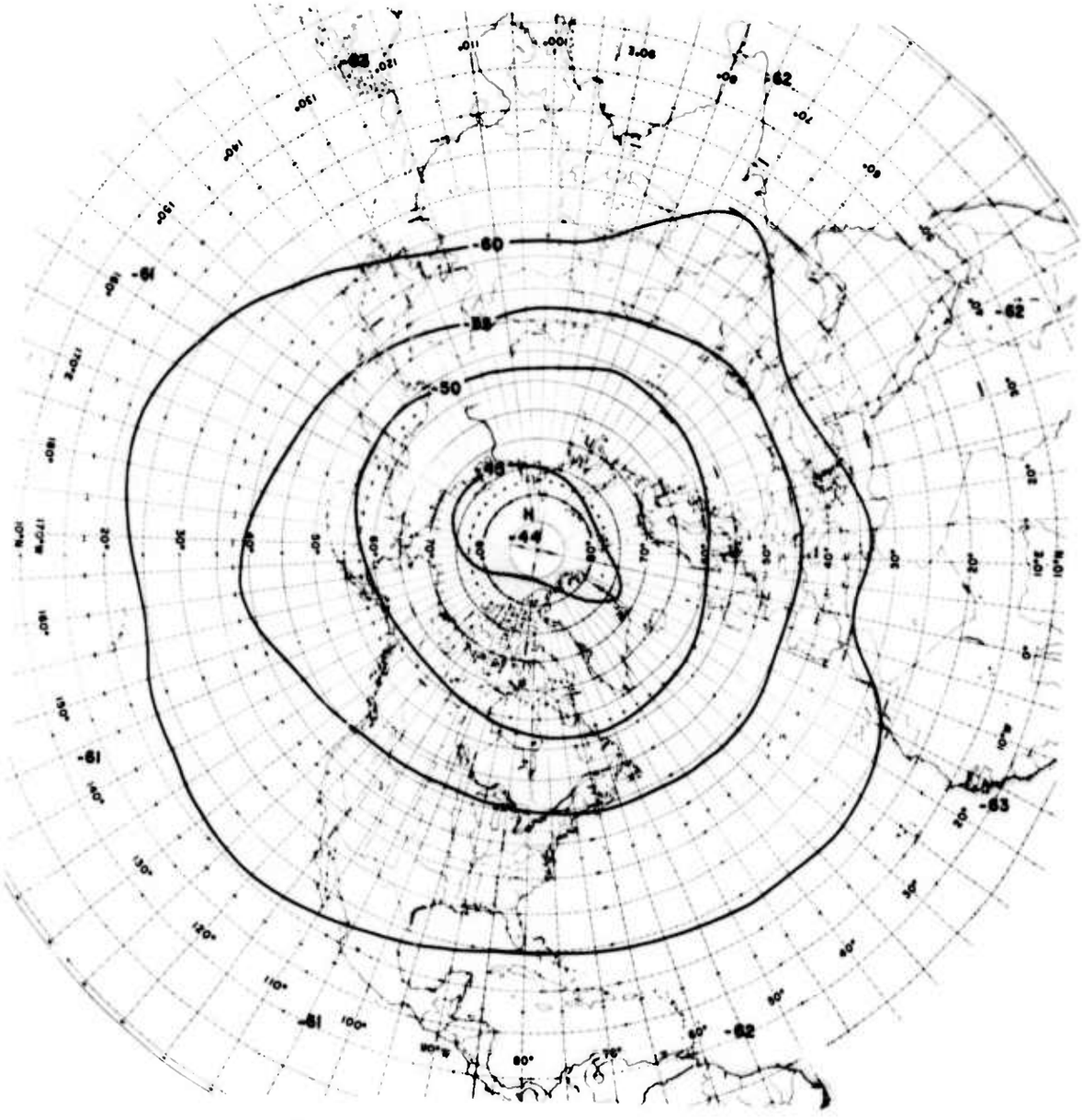
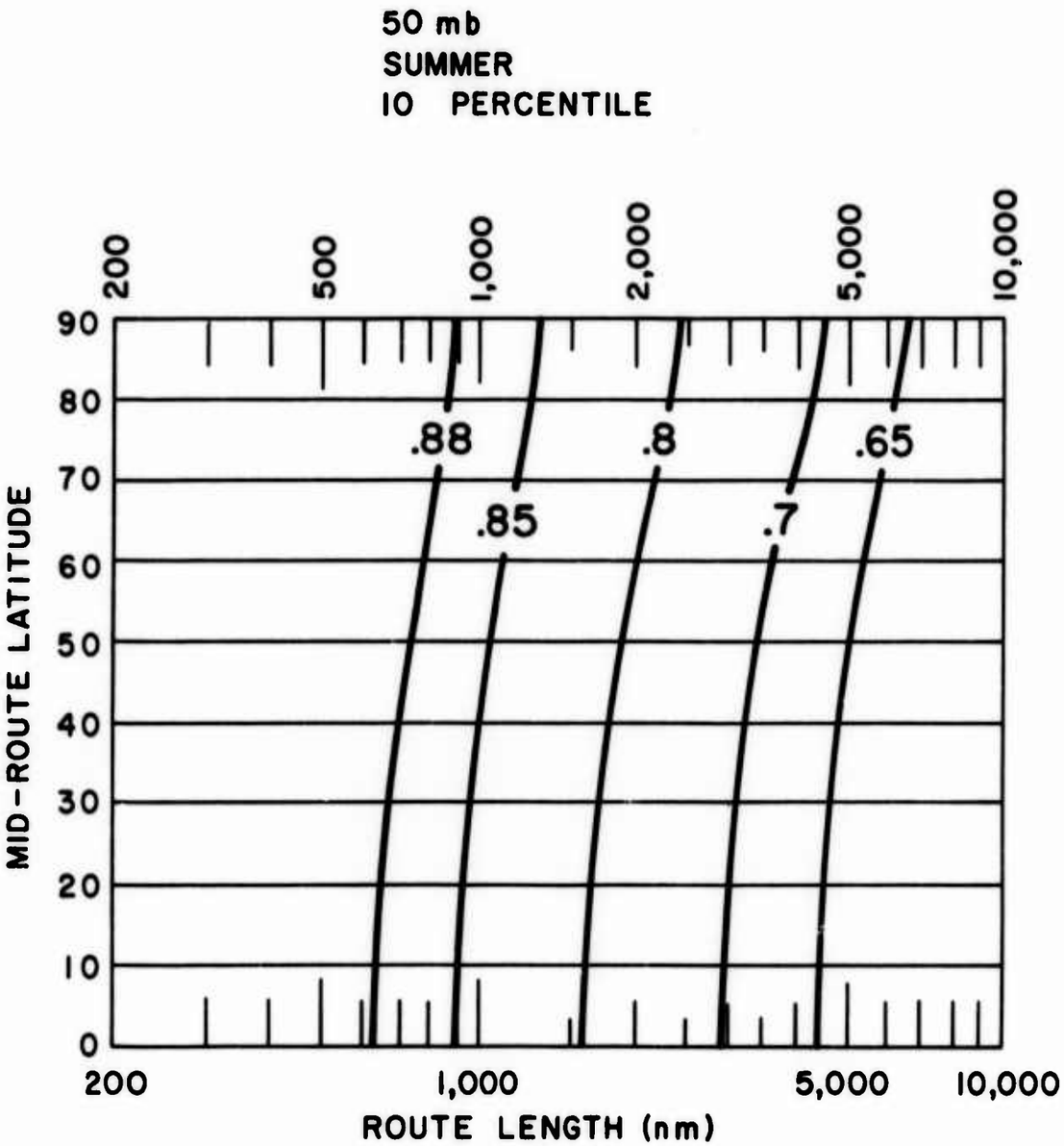
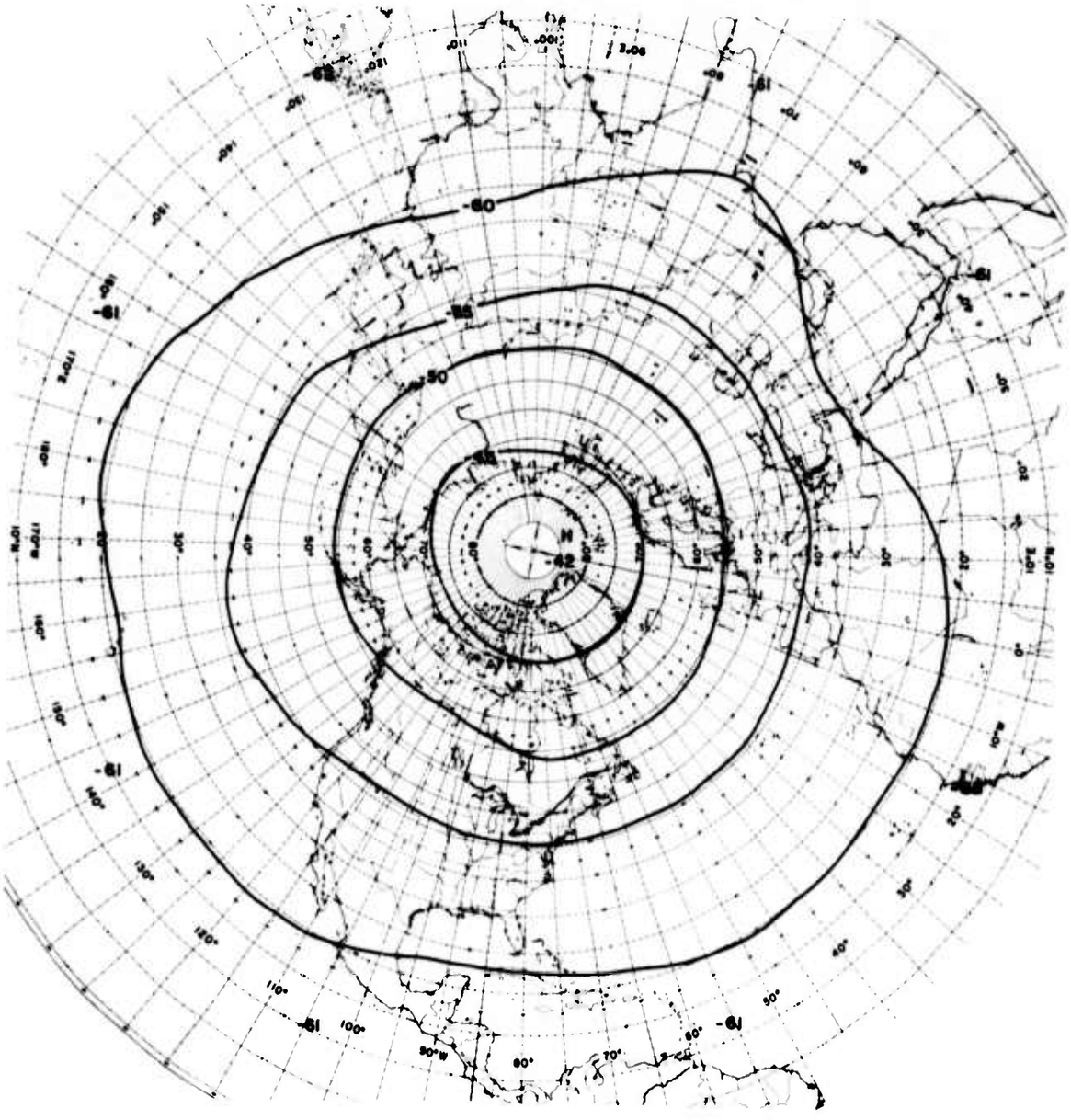


Plate 44. Temperature at 50 mb, in June, July, August, 10 Percentile



Graph 44. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page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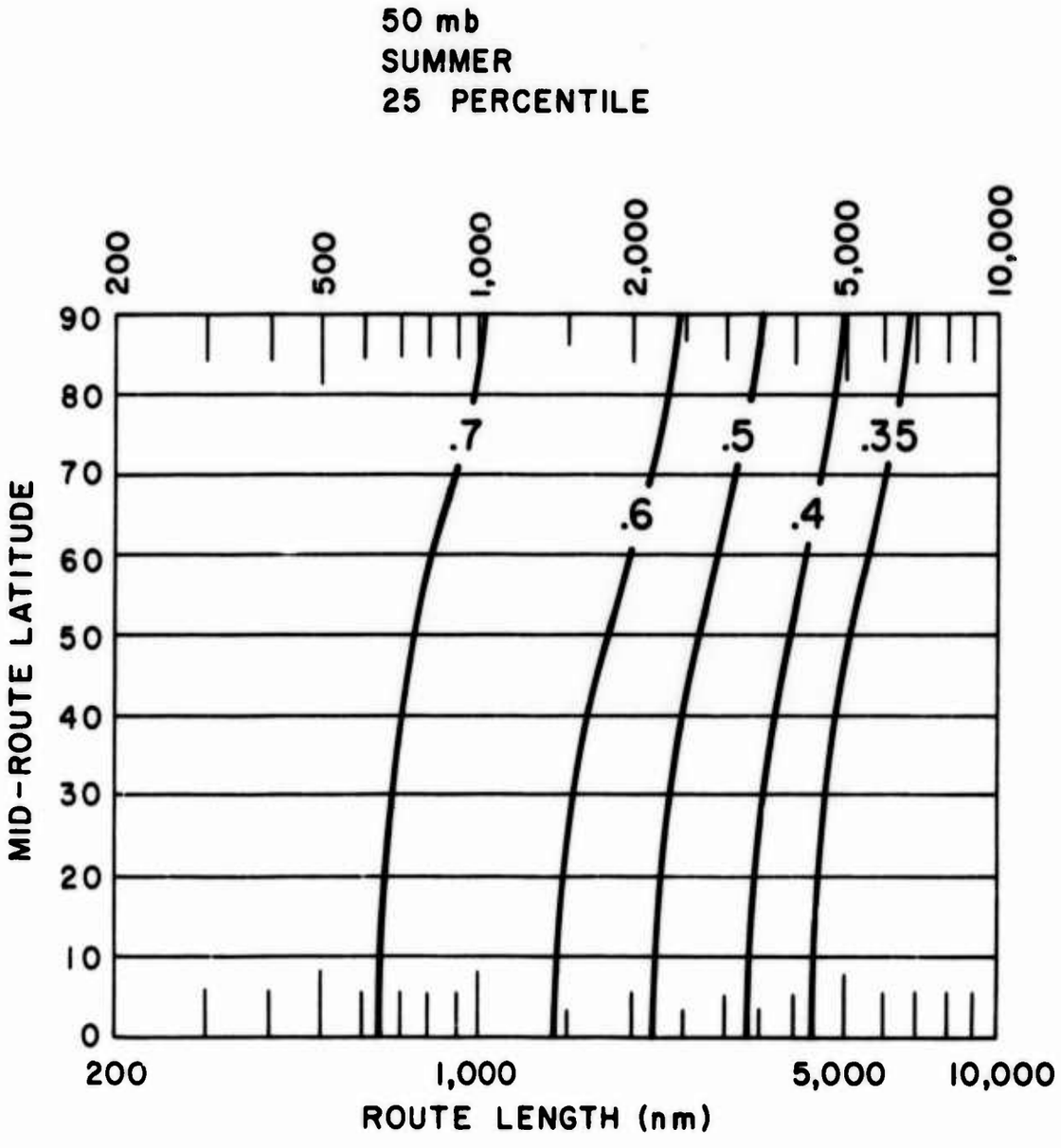


Graph 45. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

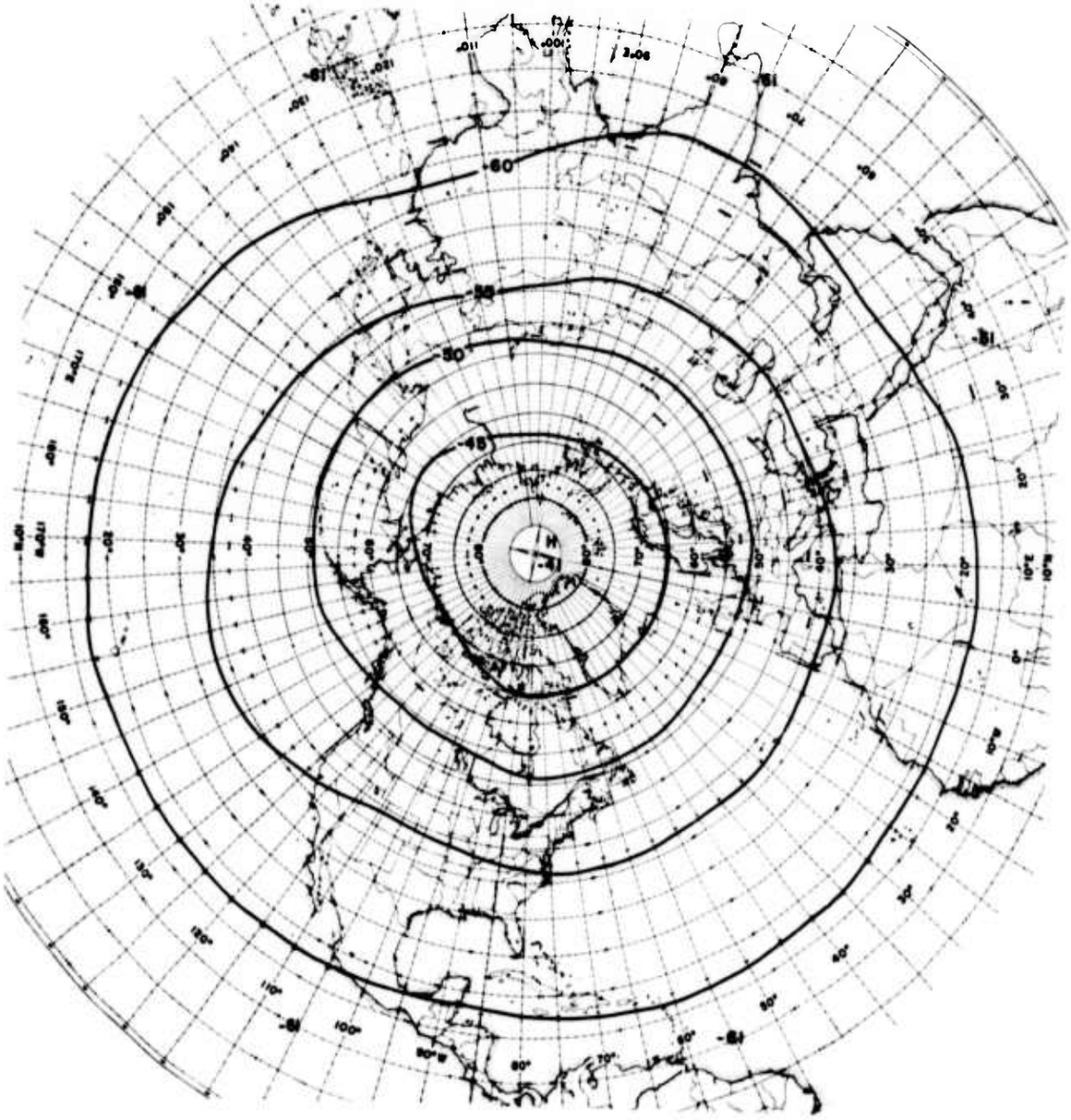
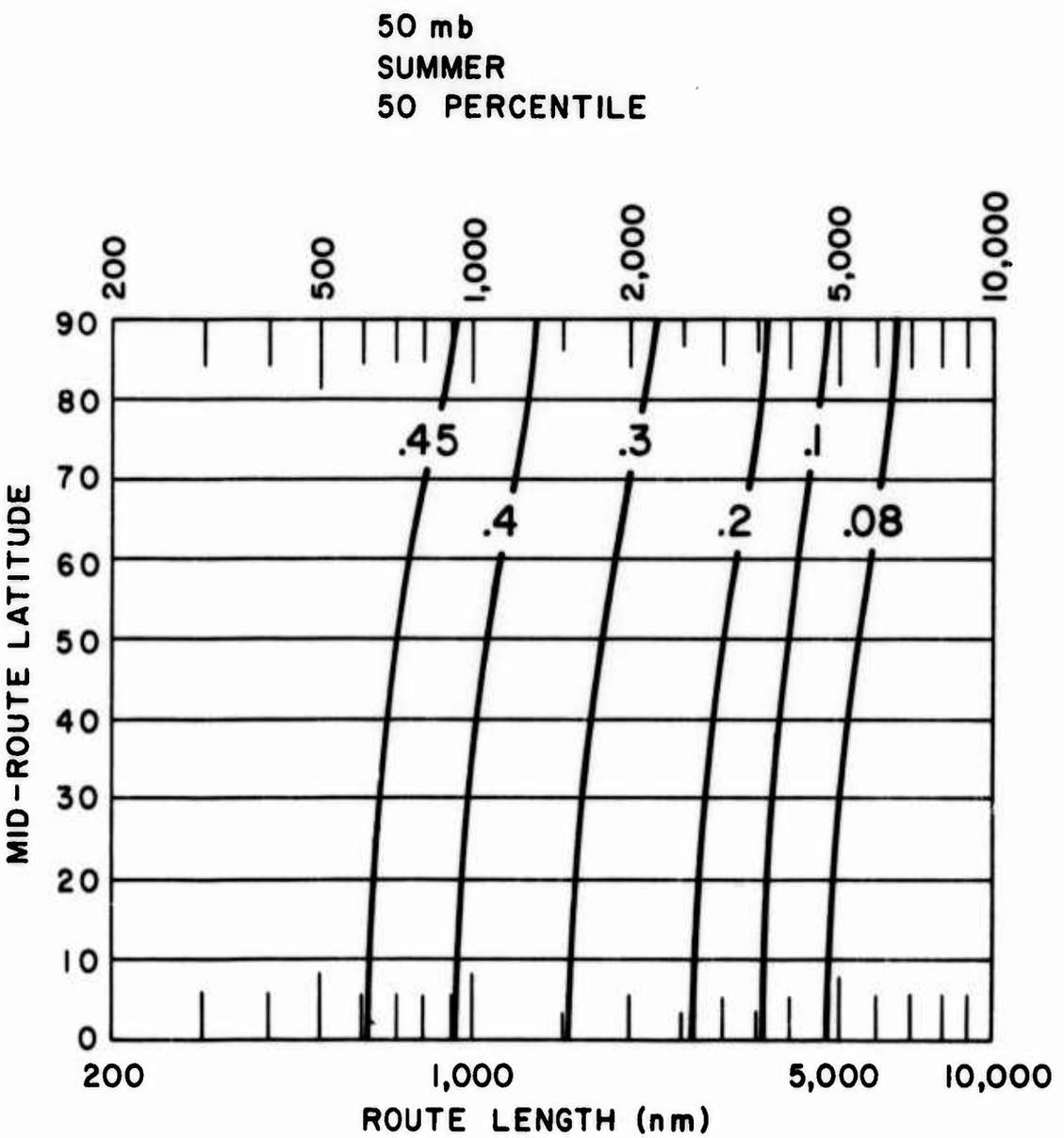


Plate 46. Temperature at 50 mb, in June, July, August, 50 Percentile



Graph 46. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

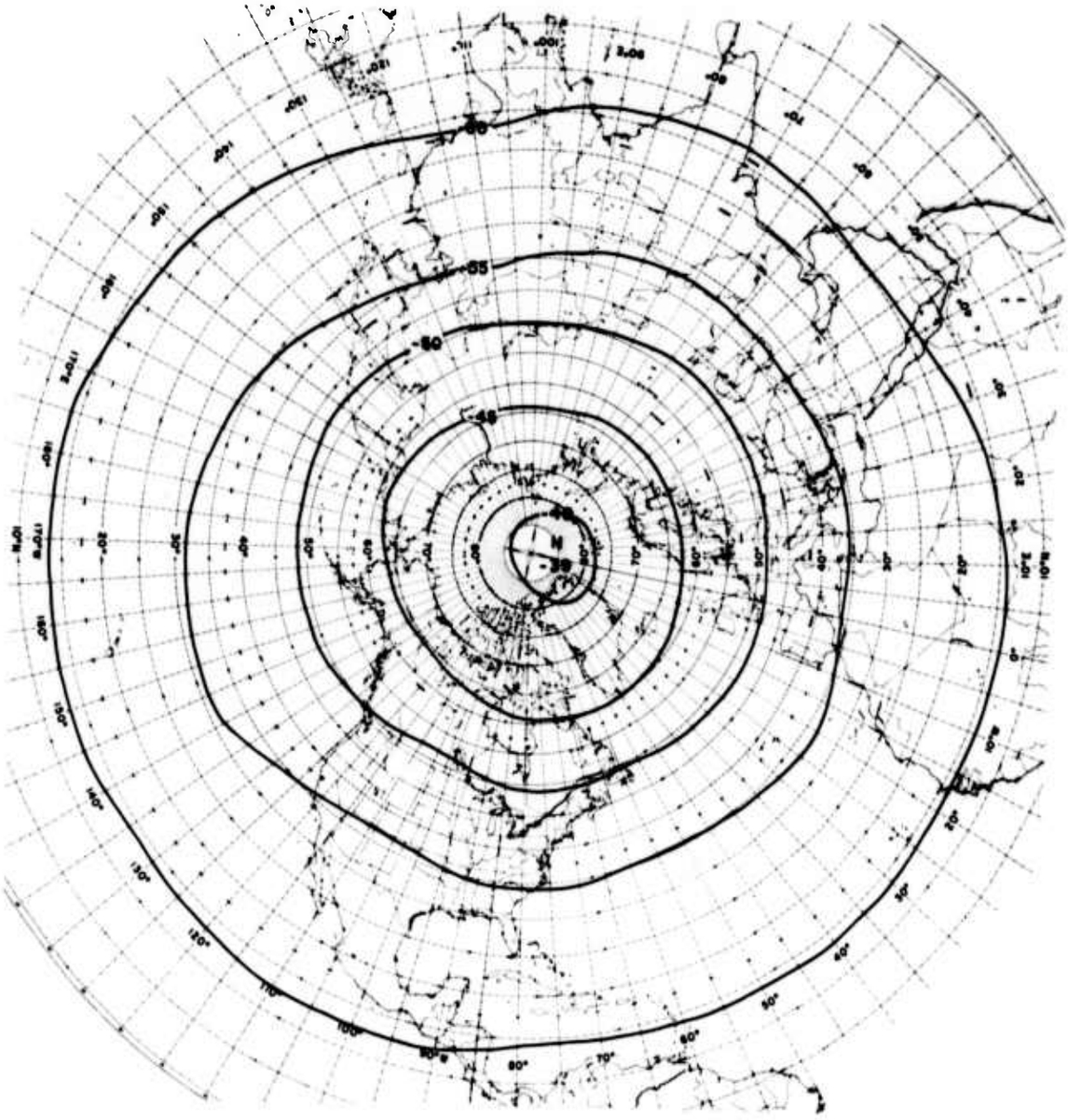
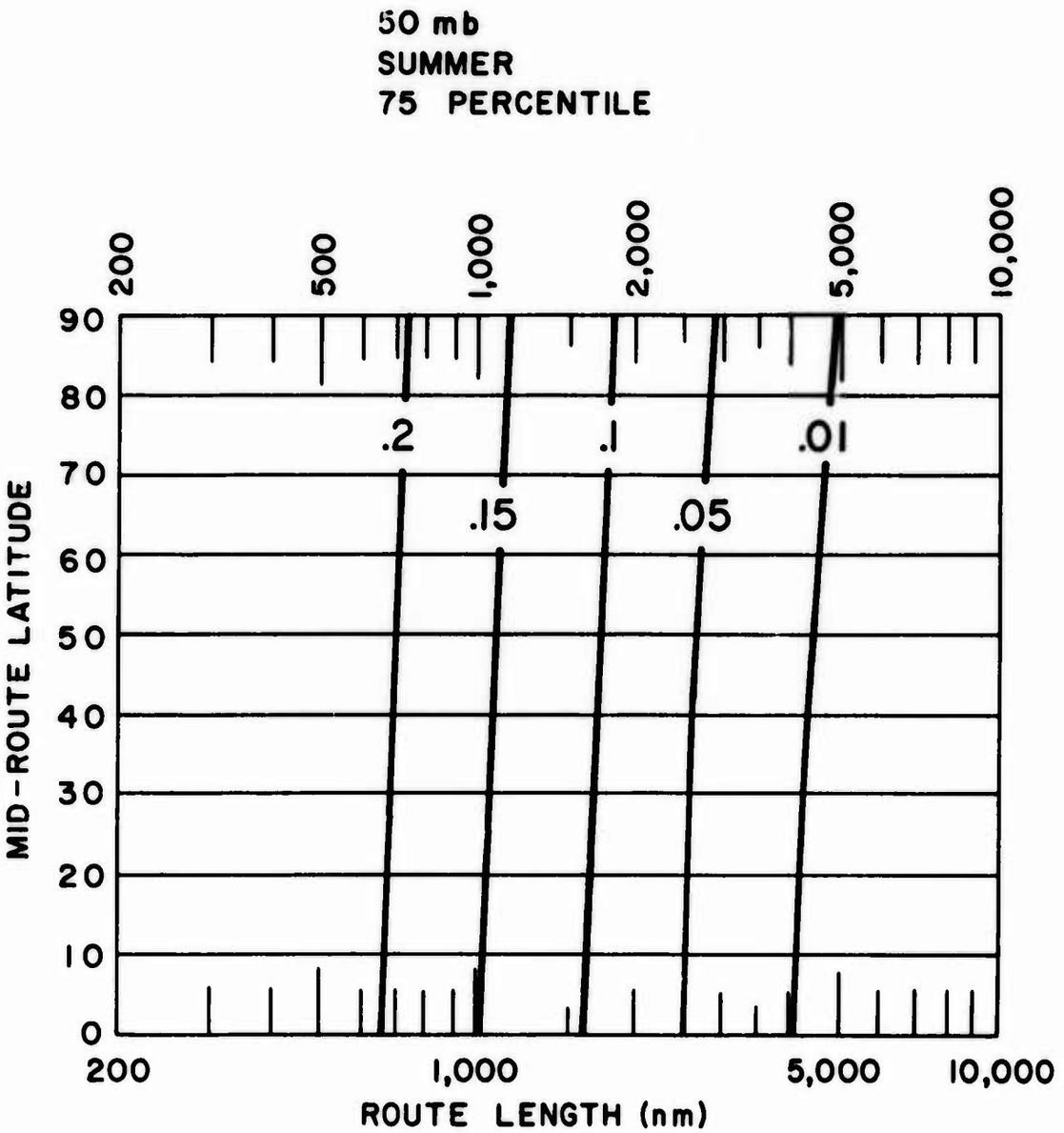


Plate 47. Temperature at 50 mb, in June, July, August, 75 Percentile



Graph 47. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

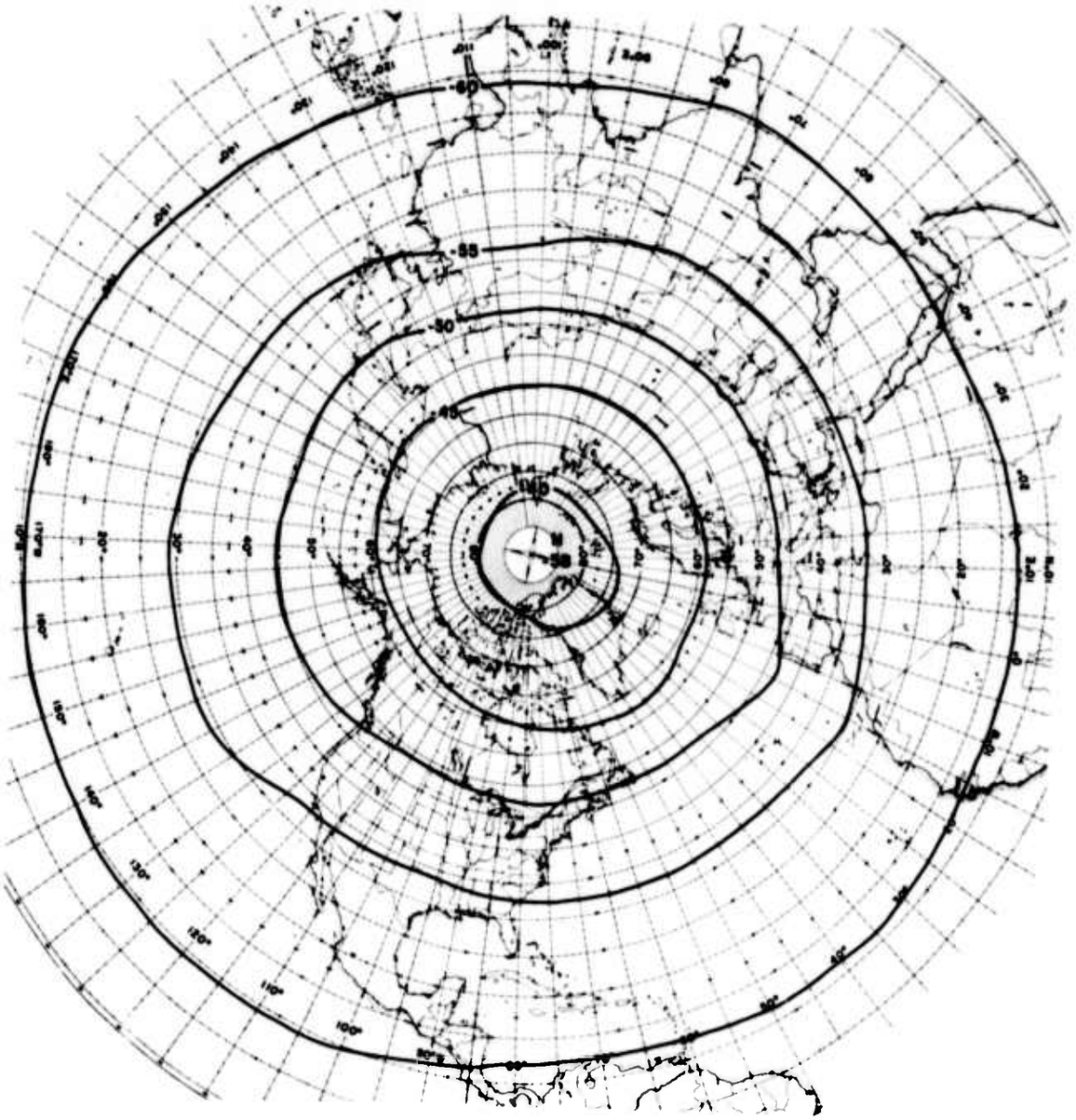
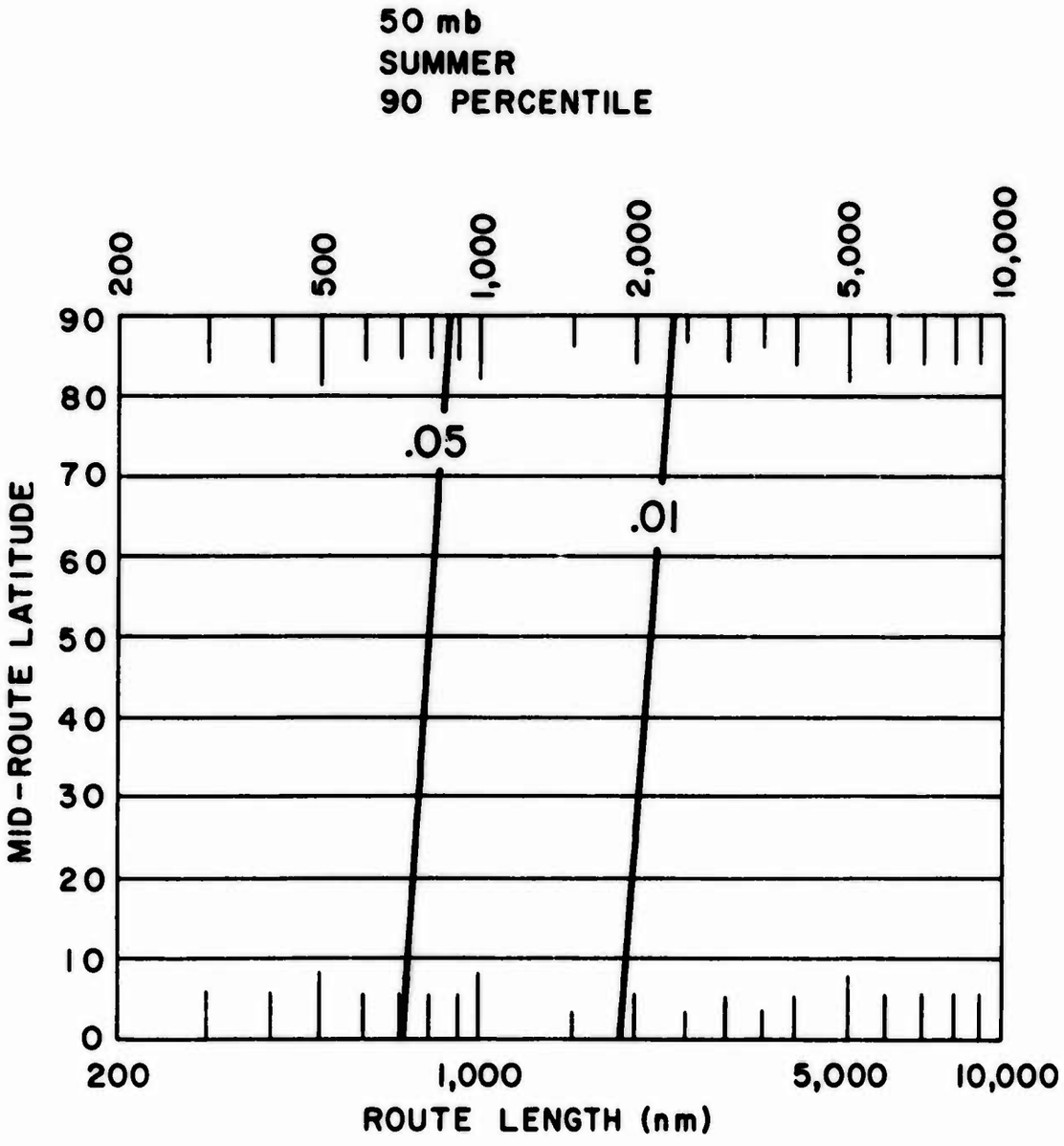


Plate 48. Temperature at 50 mb, in June, July, August, 90 Percentile



Graph 48. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

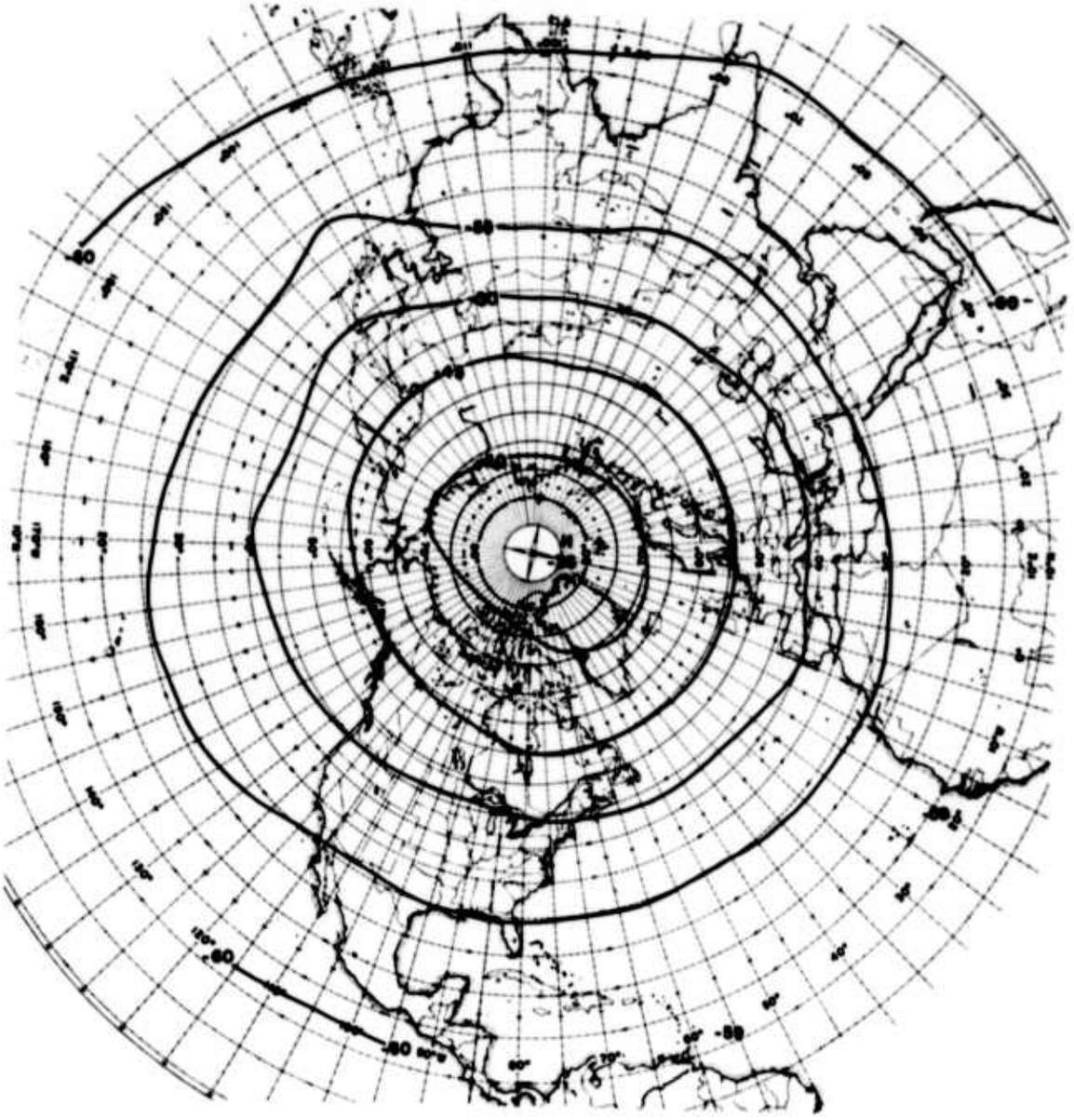
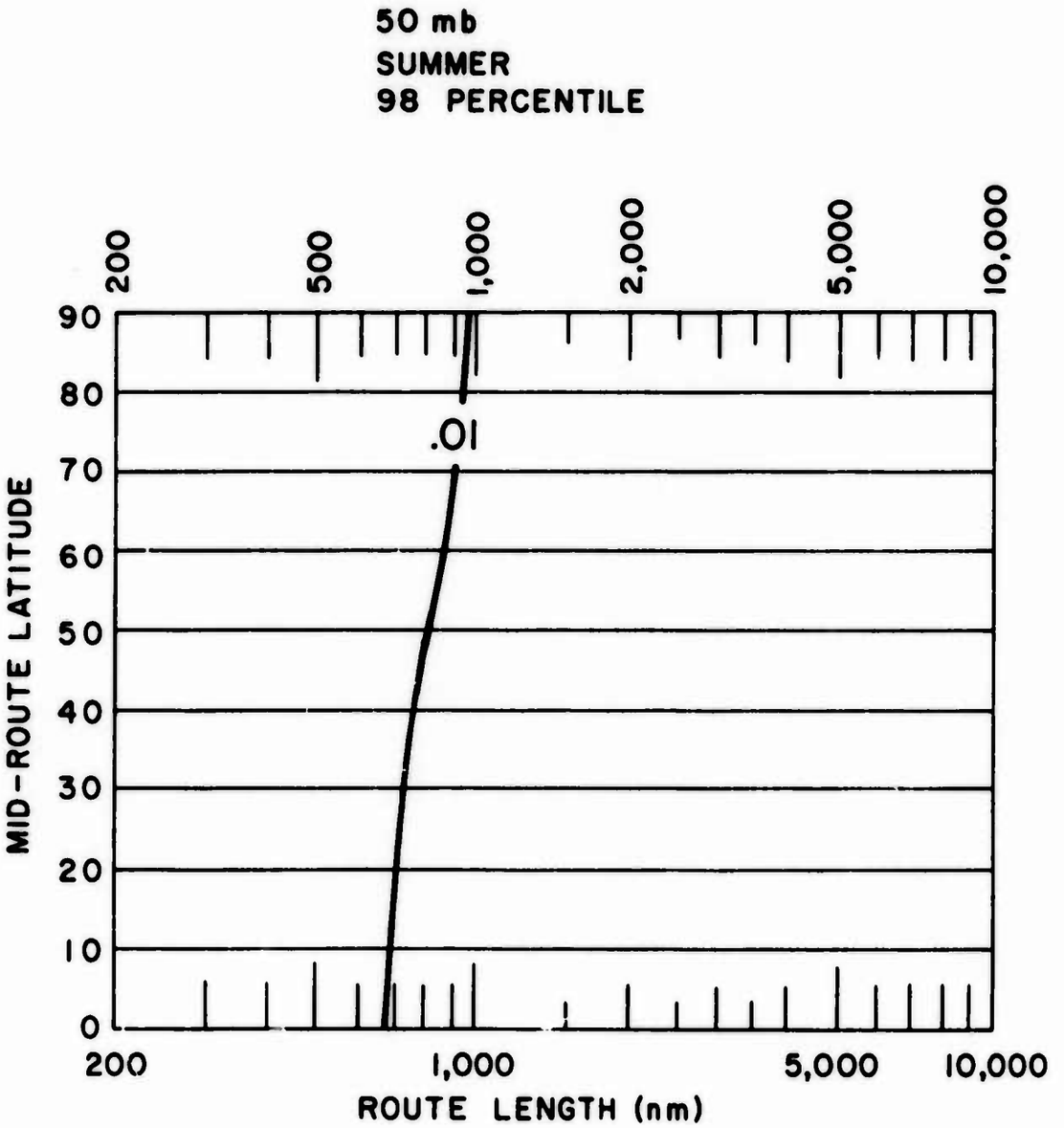


Plate 49. Temperature at 50 mb, in June, July, August, 98 Percentile



Graph 49. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

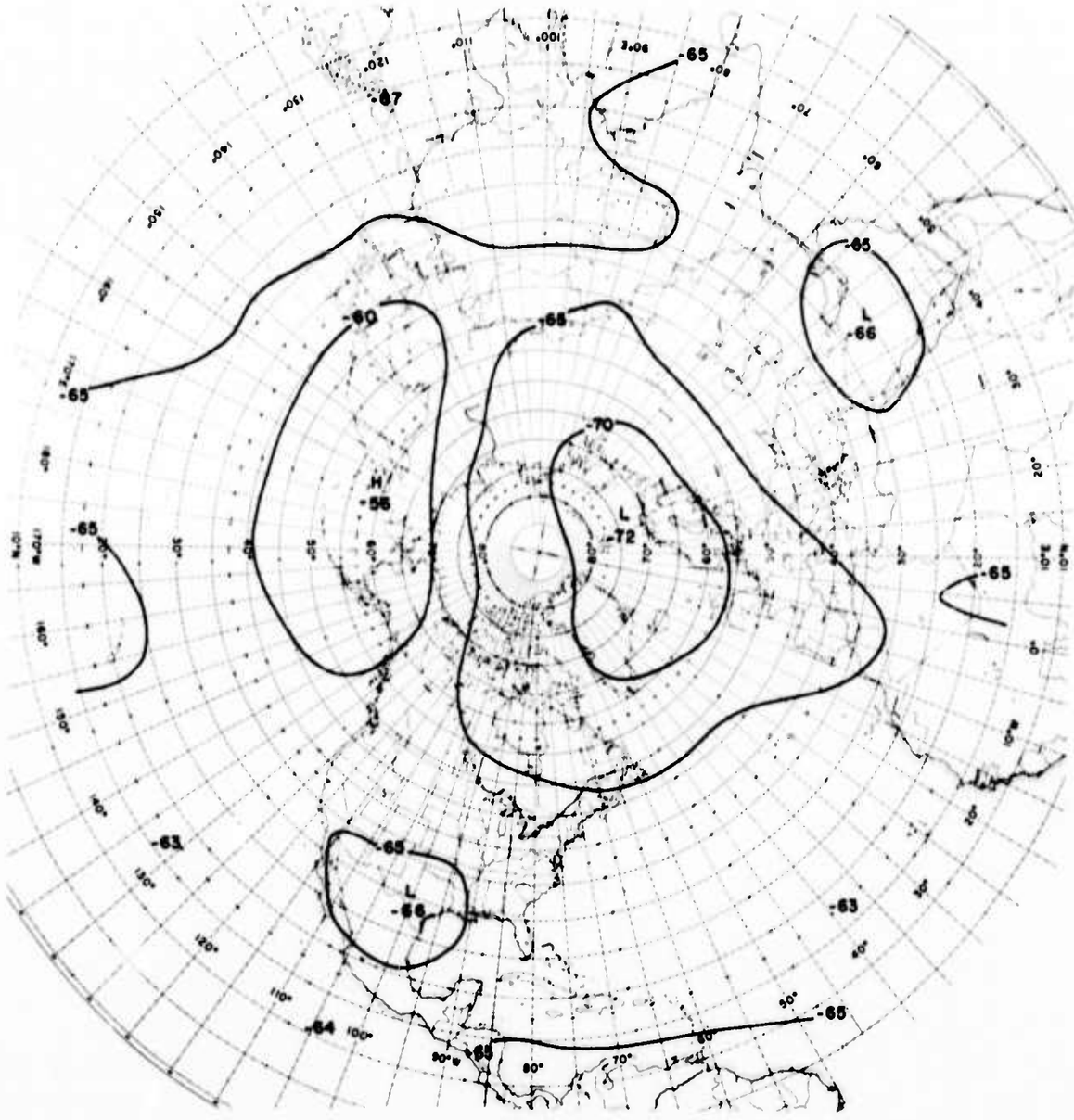
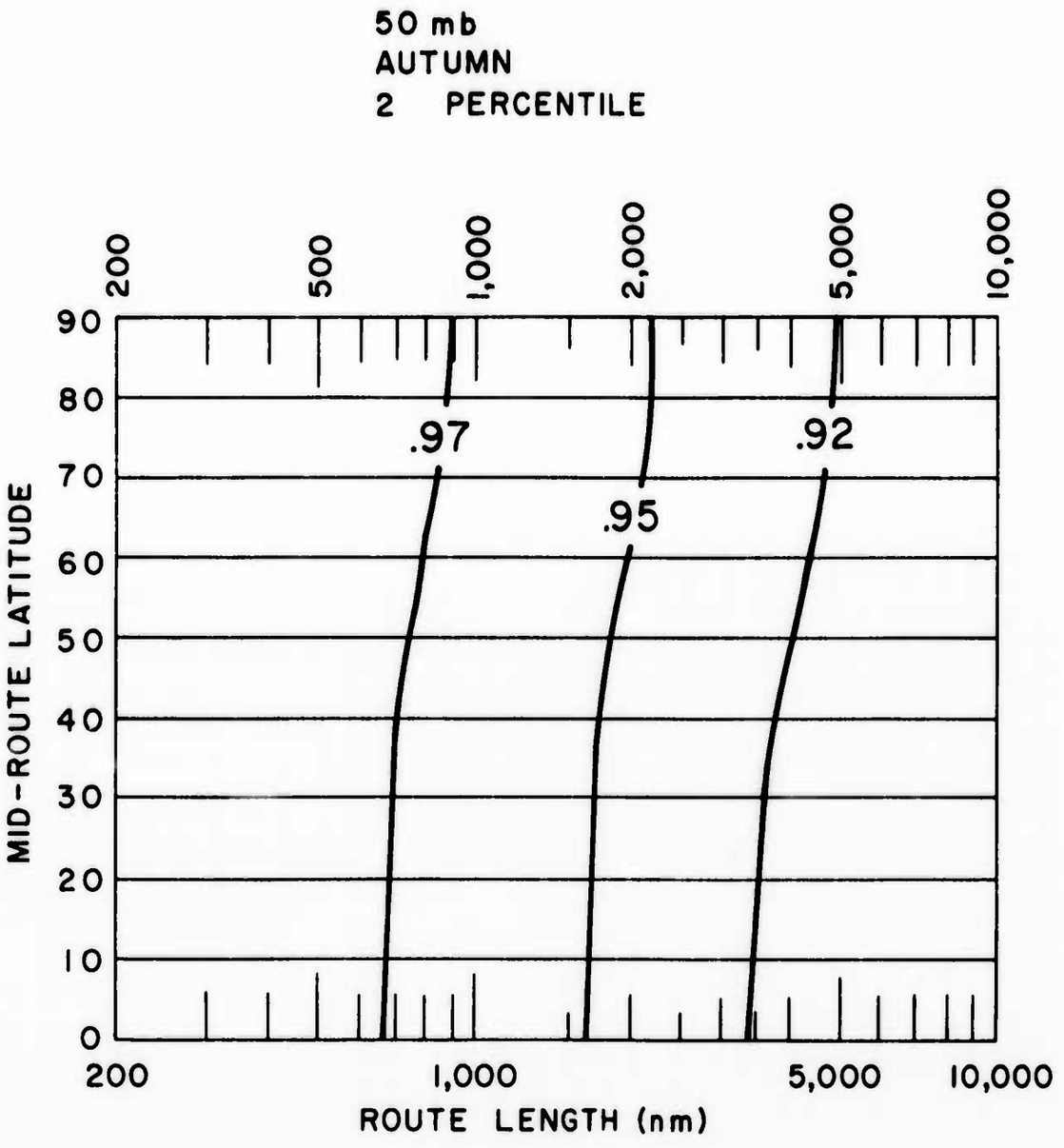


Plate 50. Temperature at 50 mb, in September, October, November, 2 Percentile



Graph 50. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

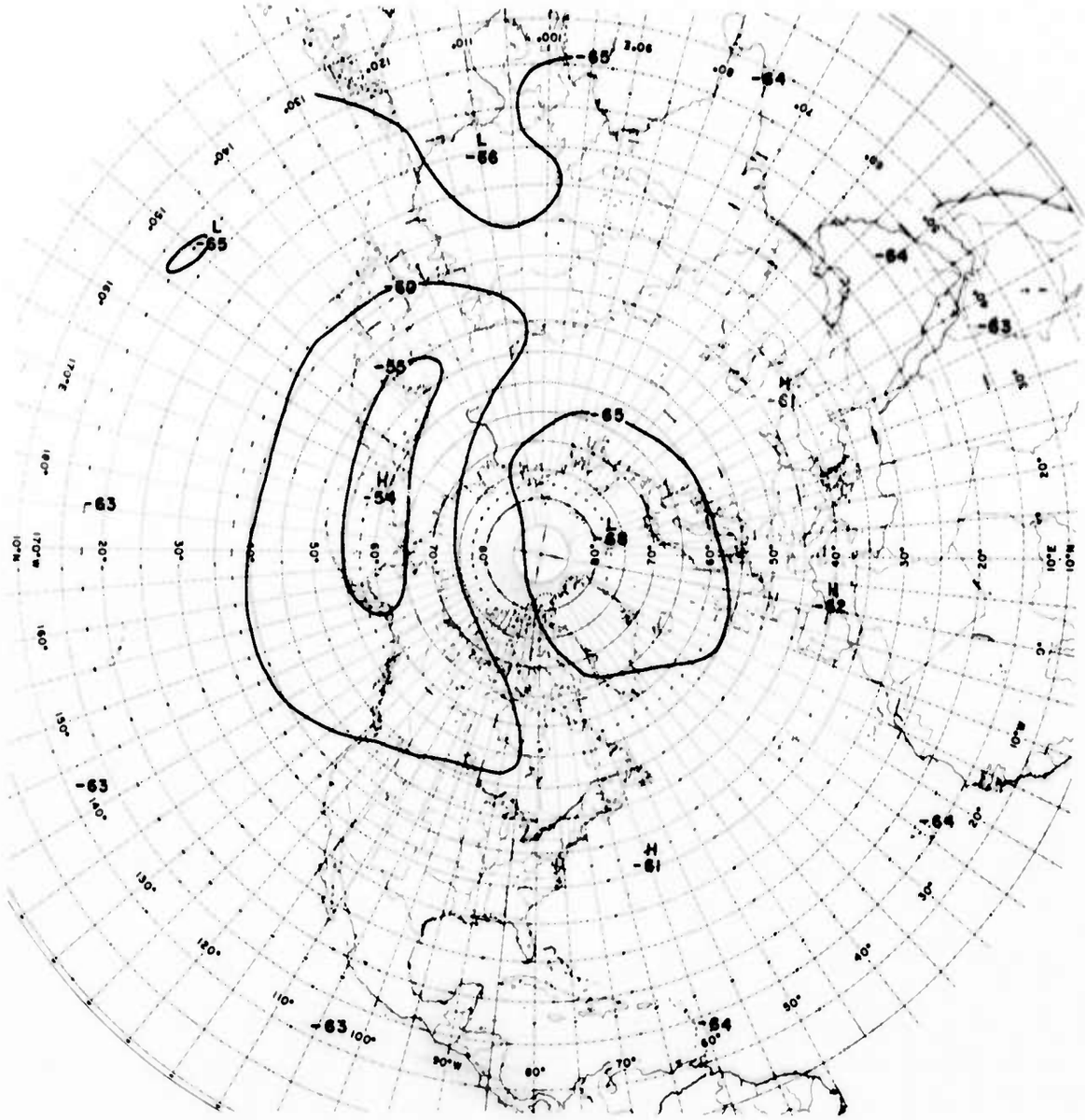
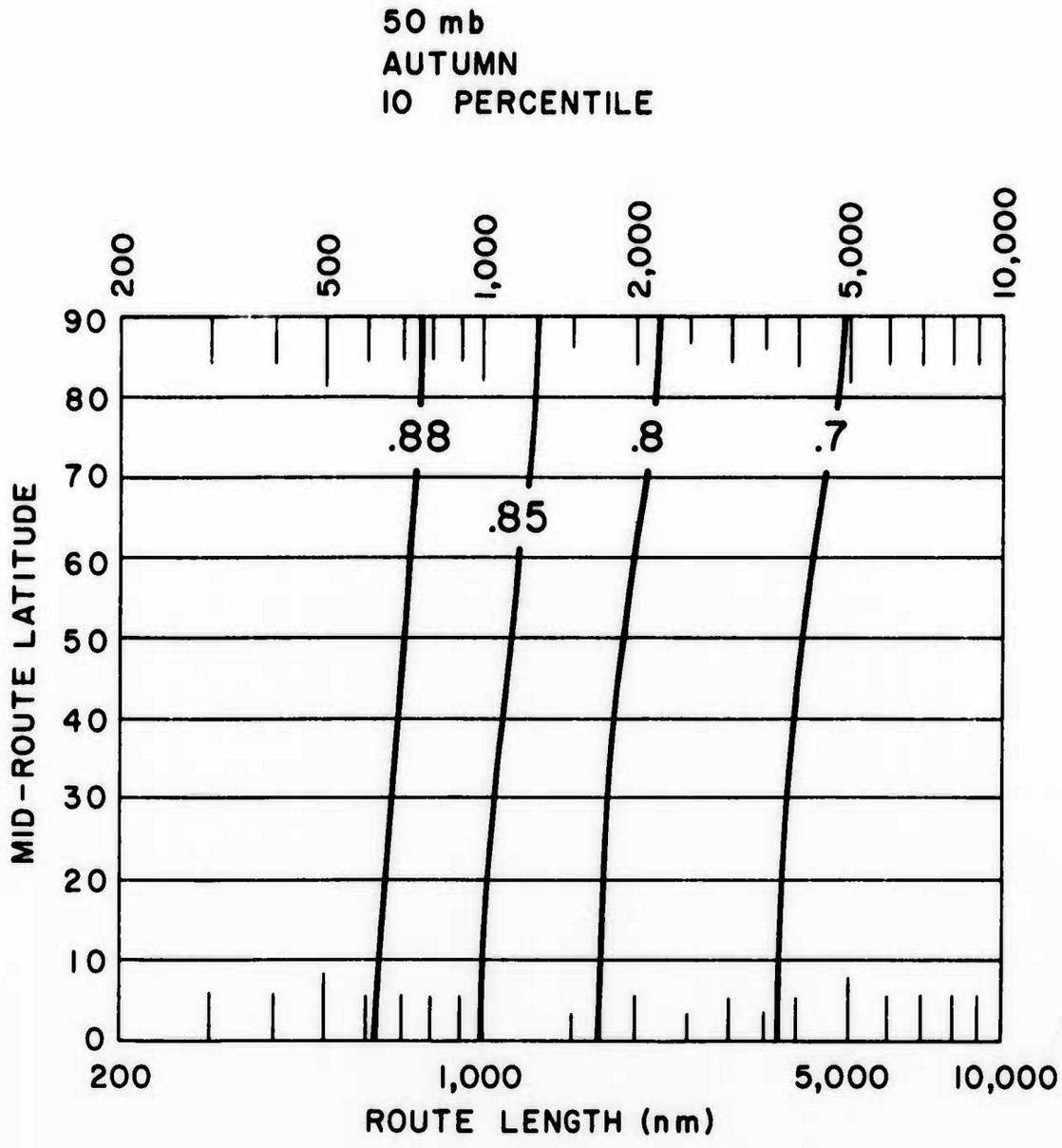


Plate 51. Temperature at 50 mb, in September, October, November, 10 Percentile



Graph 51. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

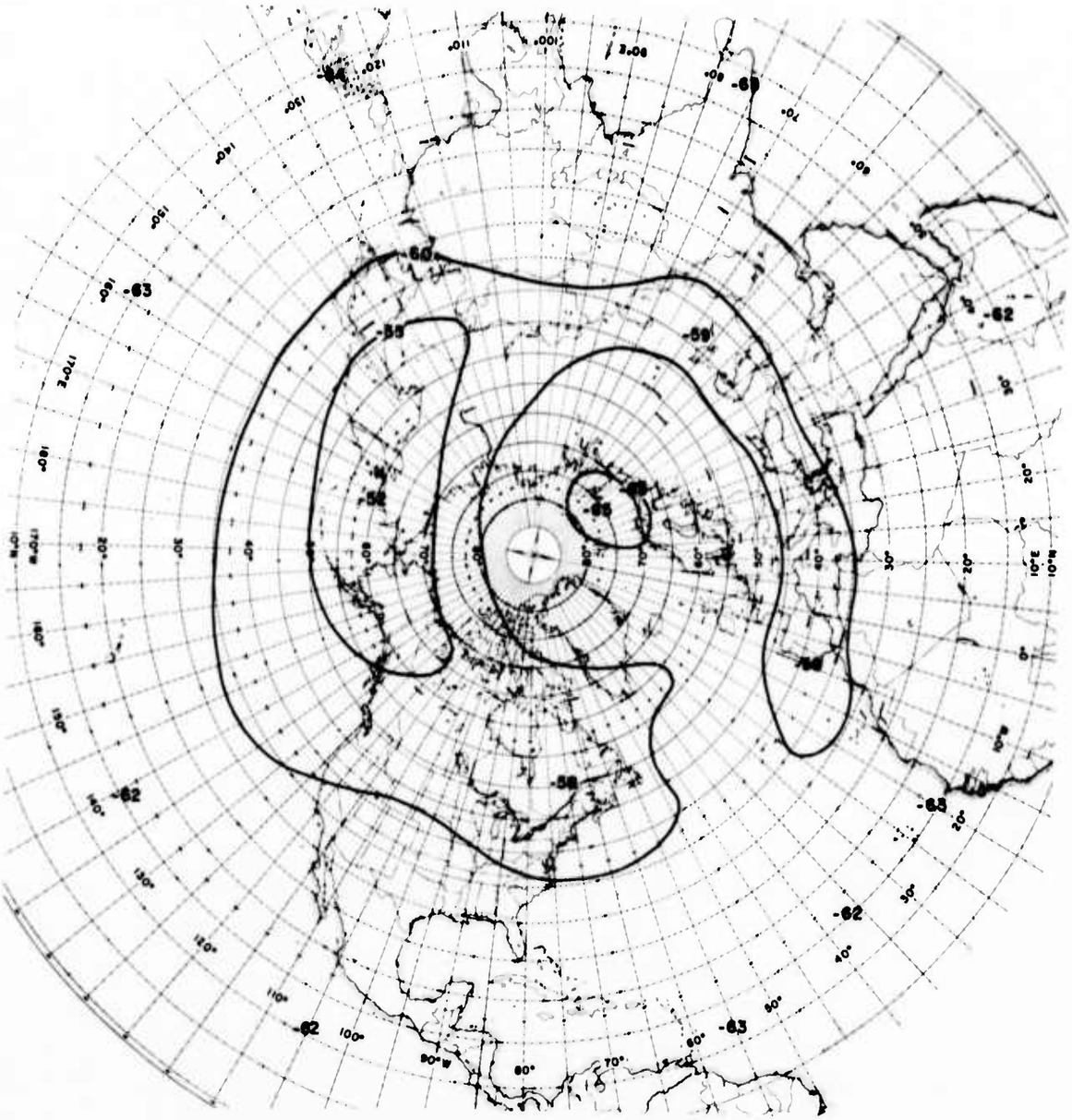
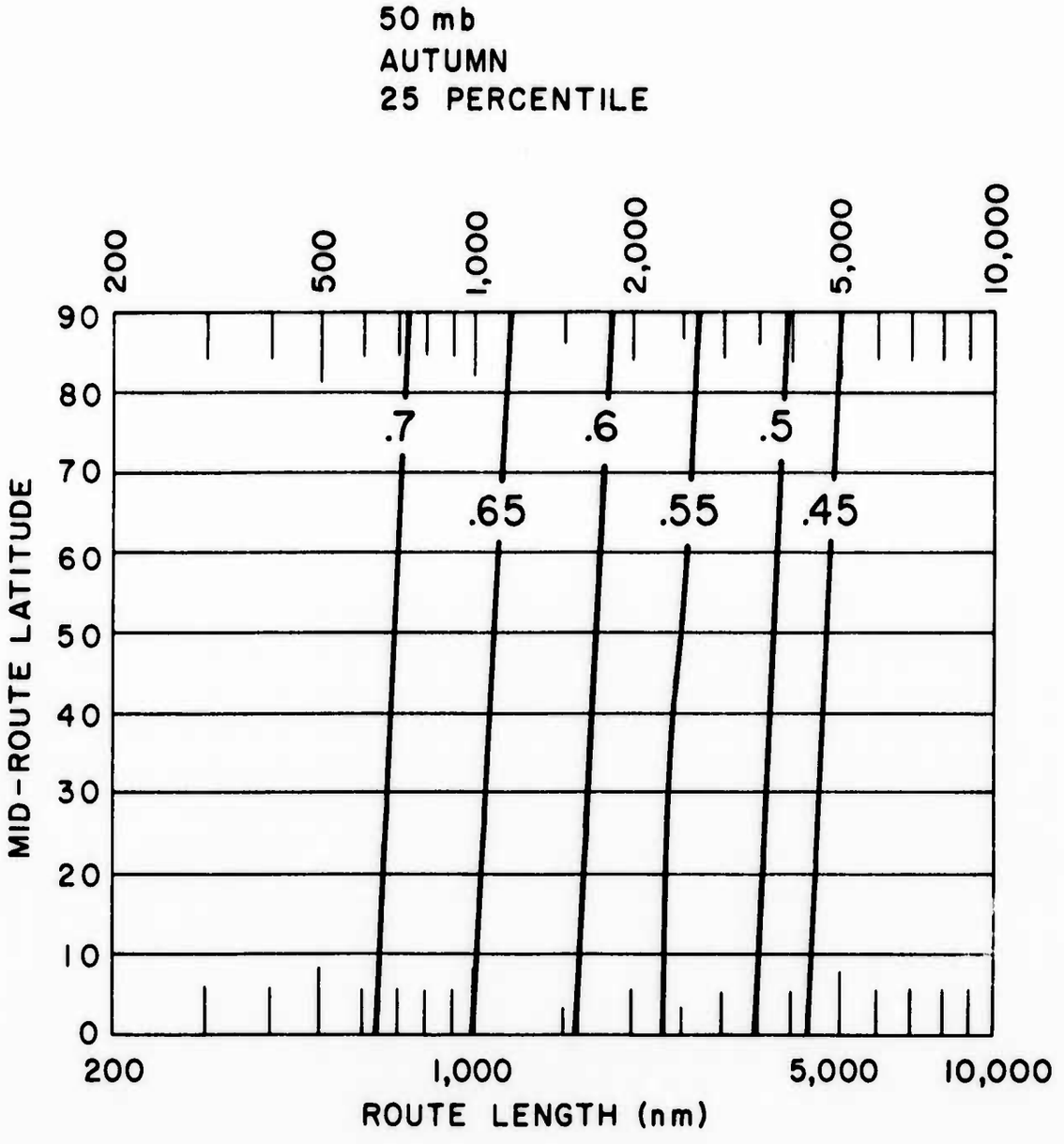


Plate 52. Temperature at 50 mb, in September, October, November, 25 Percentile



Graph 52. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

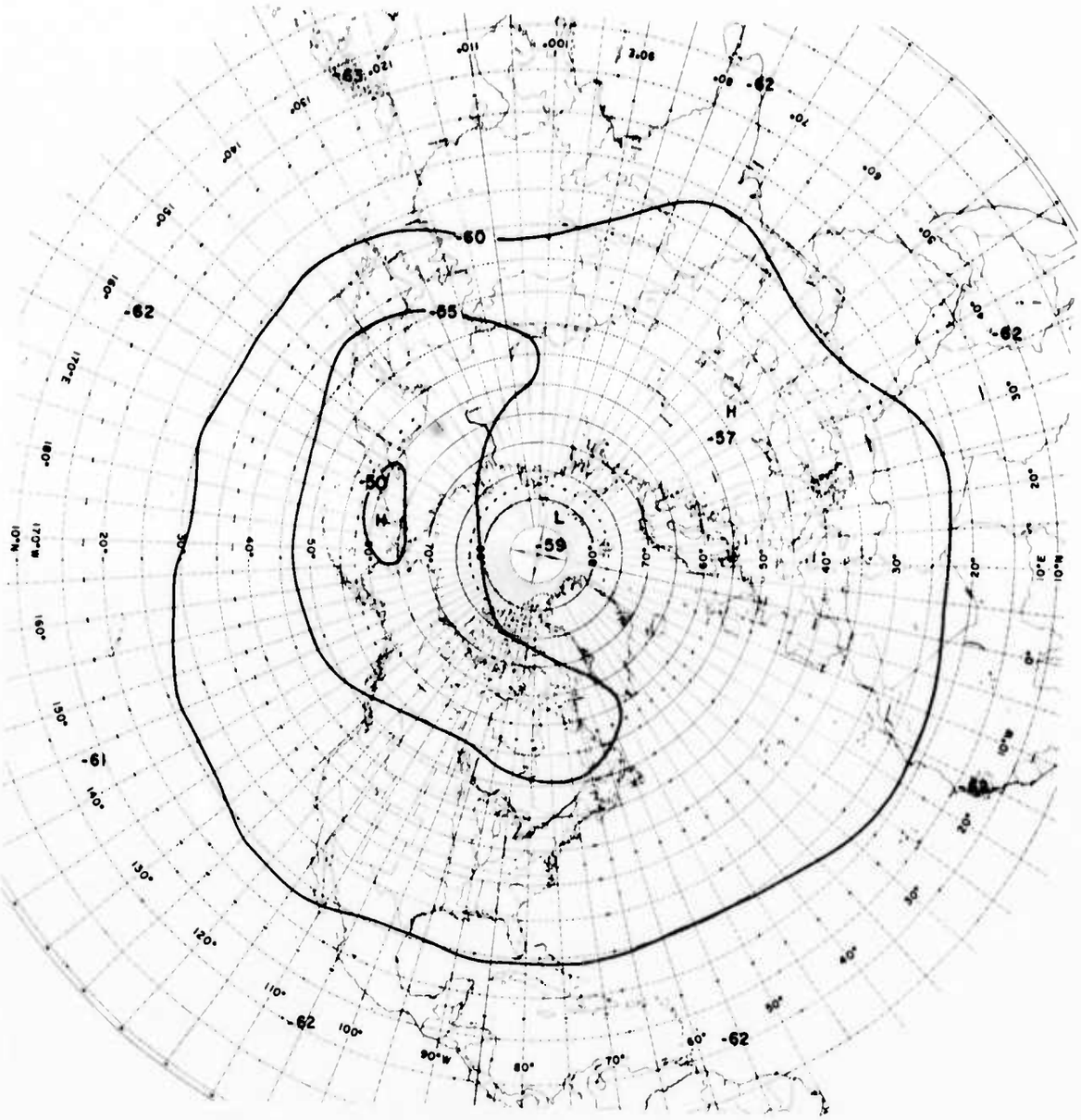
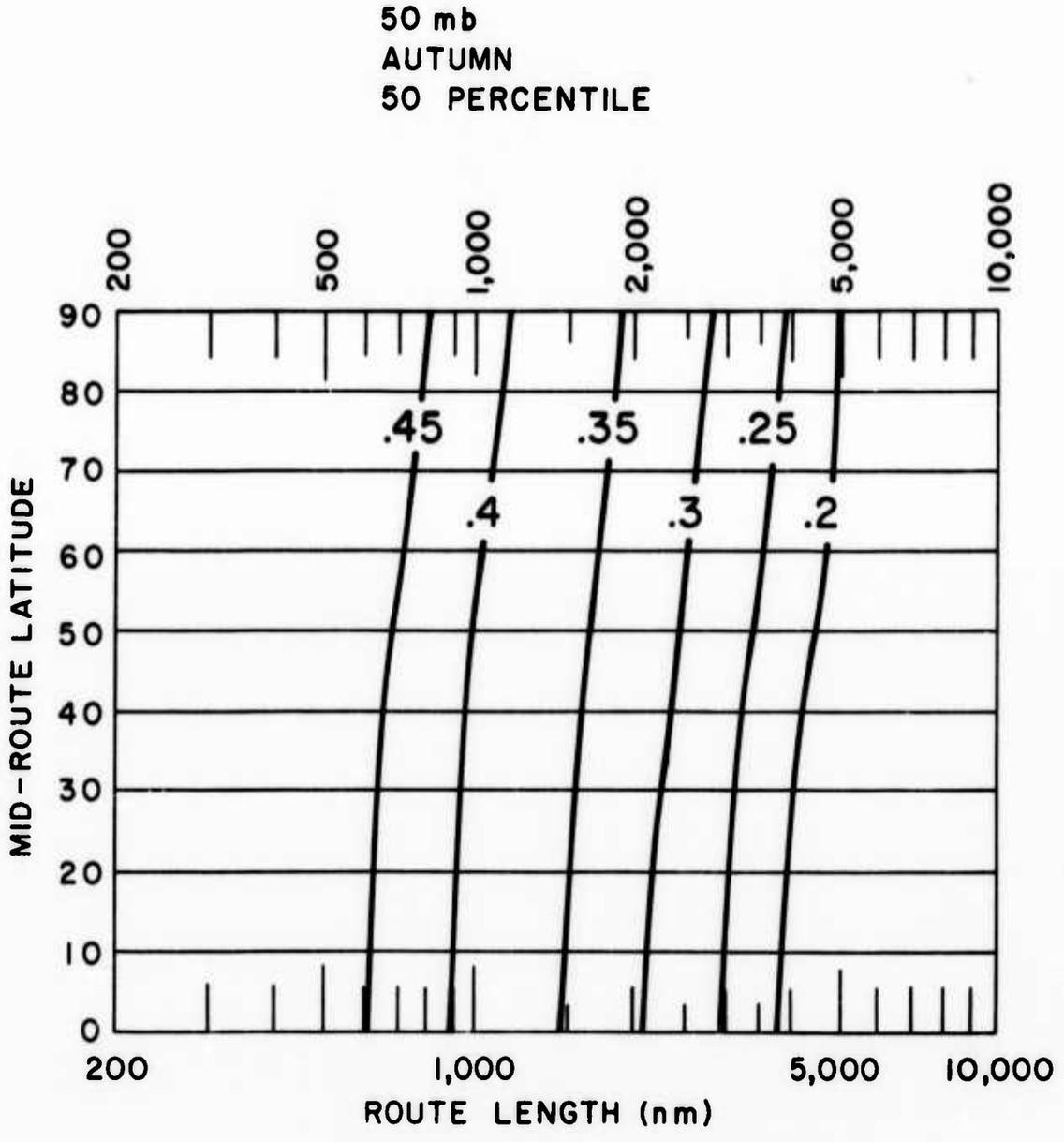


Plate 53. Temperature at 50 mb, in September, October, November, 50 Percentile



Graph 53. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

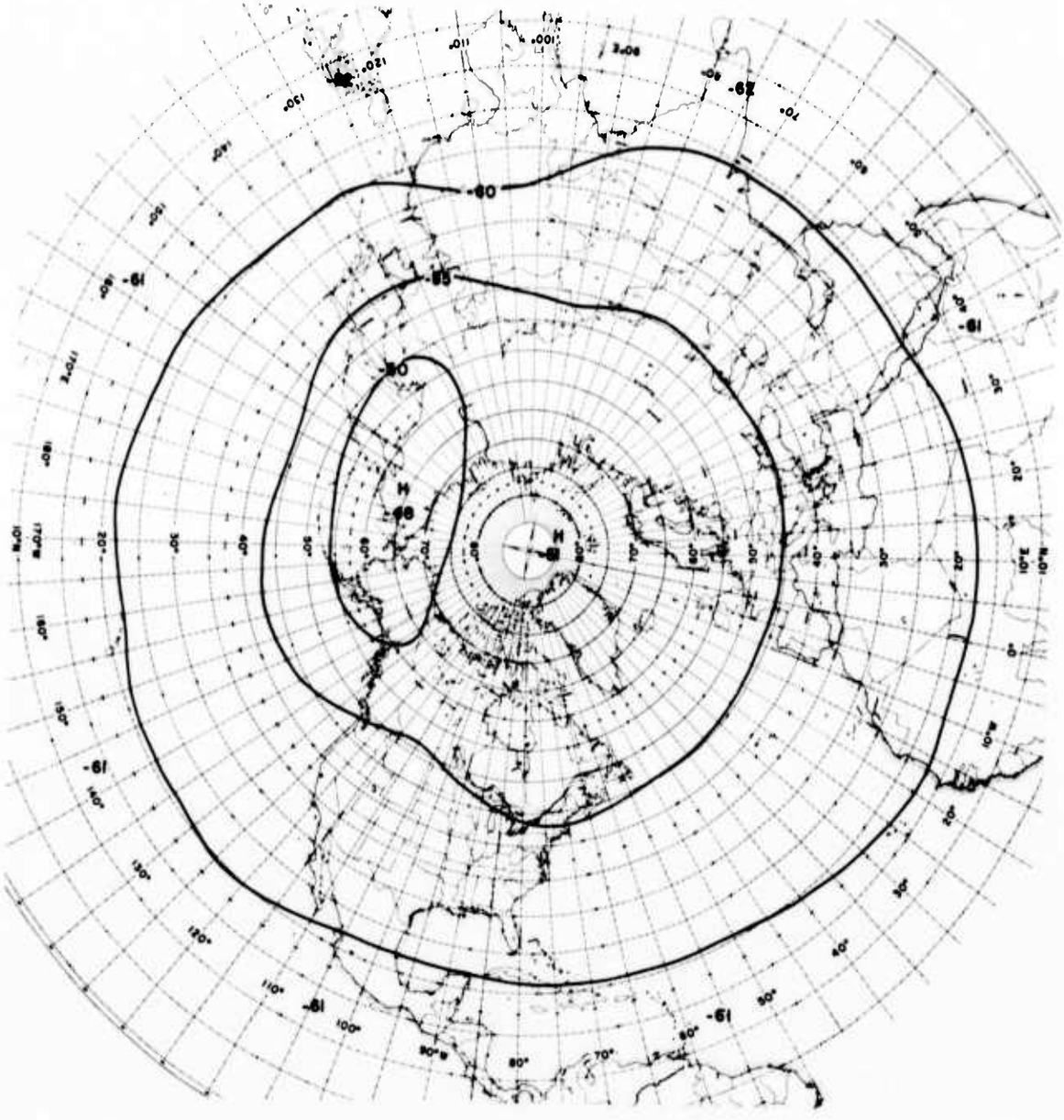
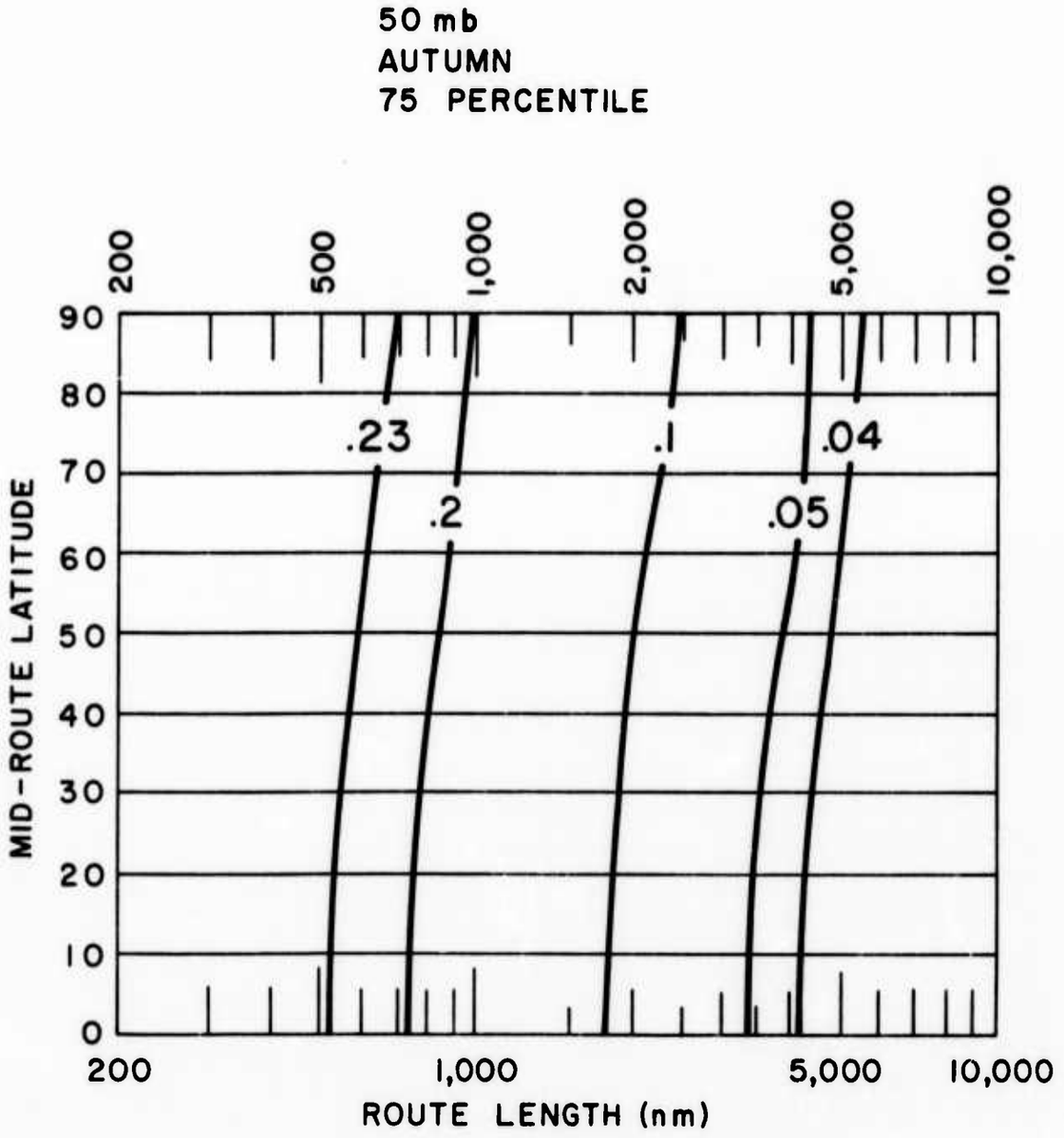


Plate 54. Temperature at 50 mb, in September, October, November, 75 Percentile



Graph 54. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

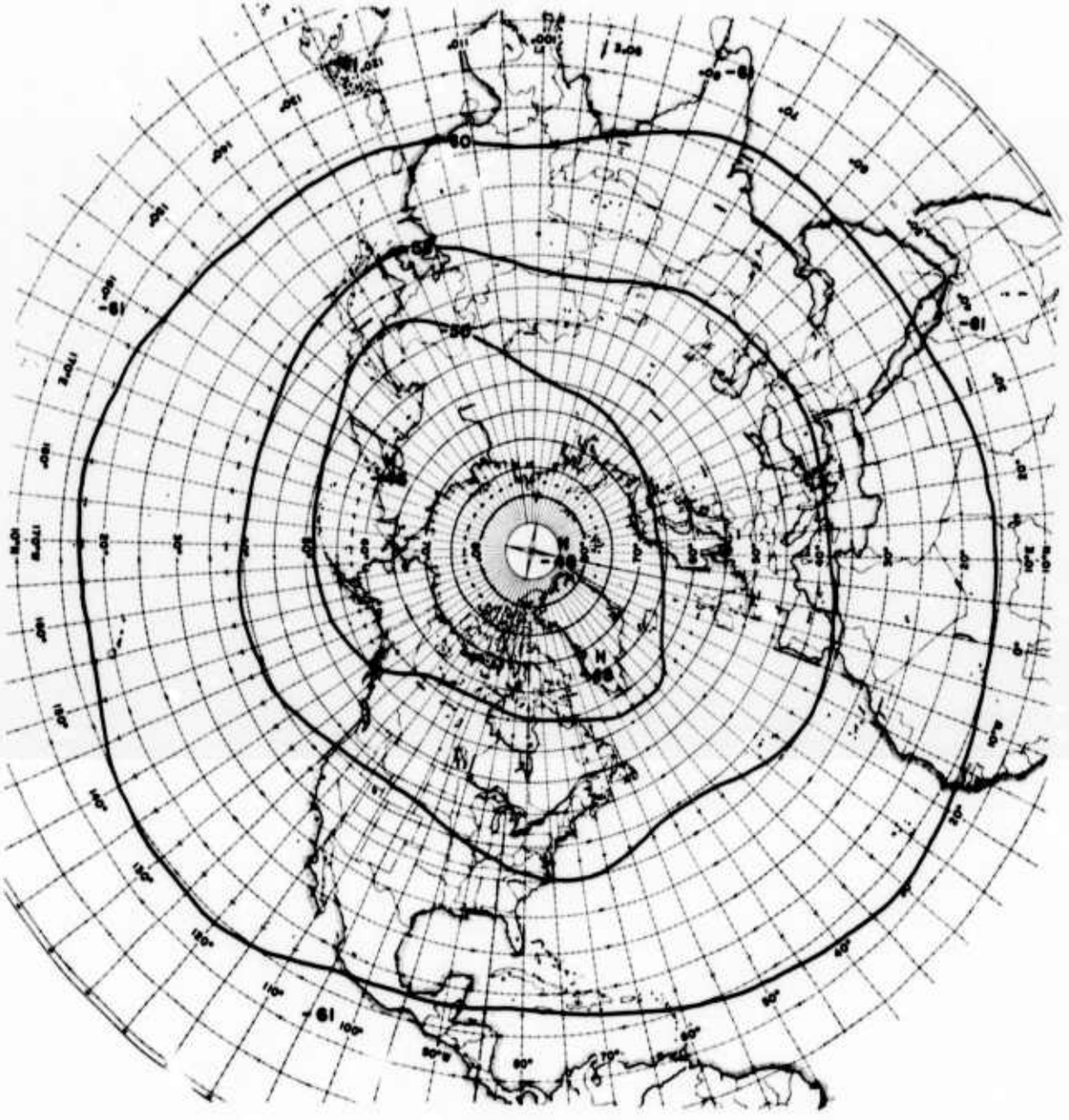
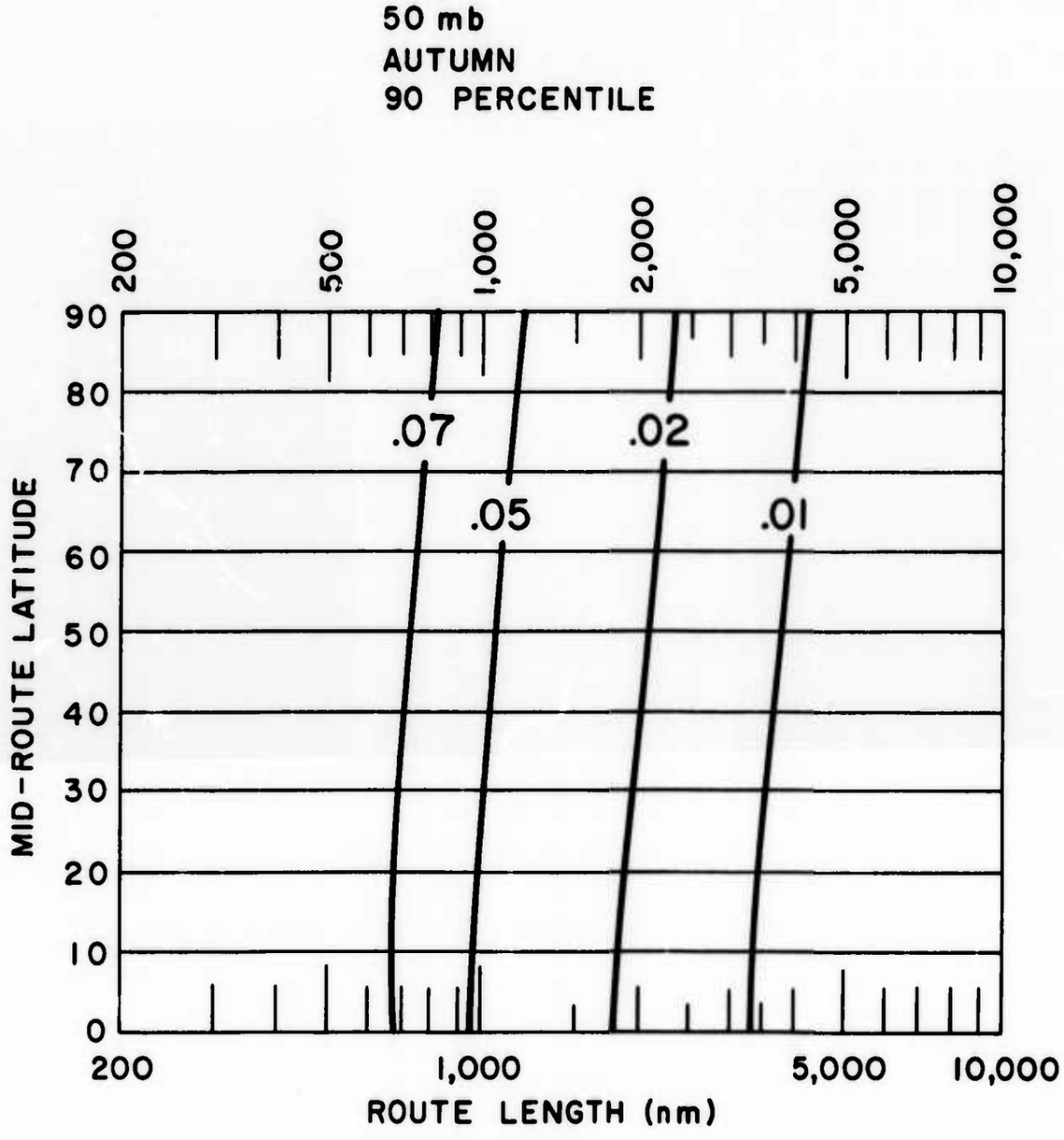


Plate 55. Temperature at 50 mb, in September, October, November, 90 Percentile



Graph 55. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

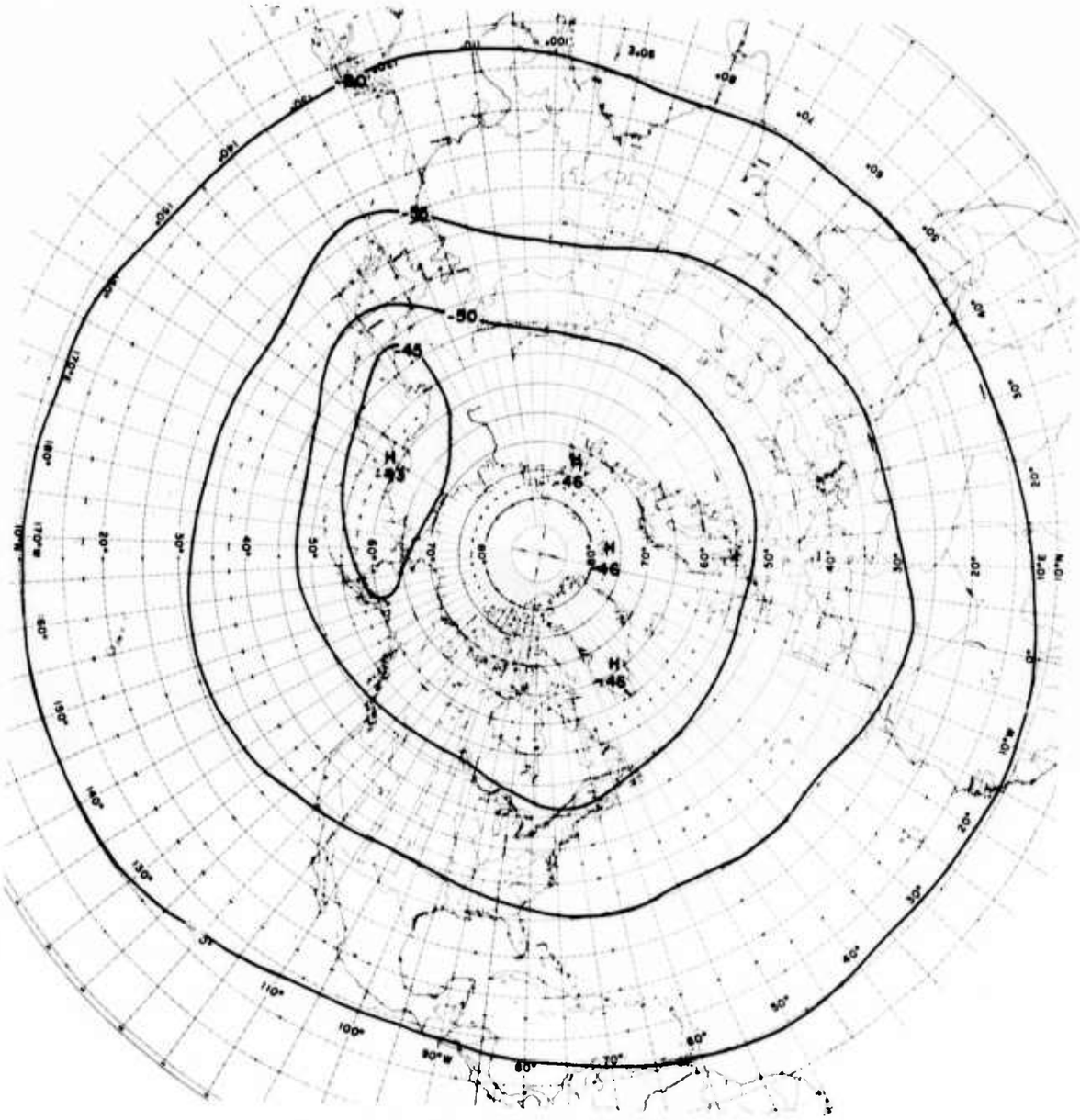
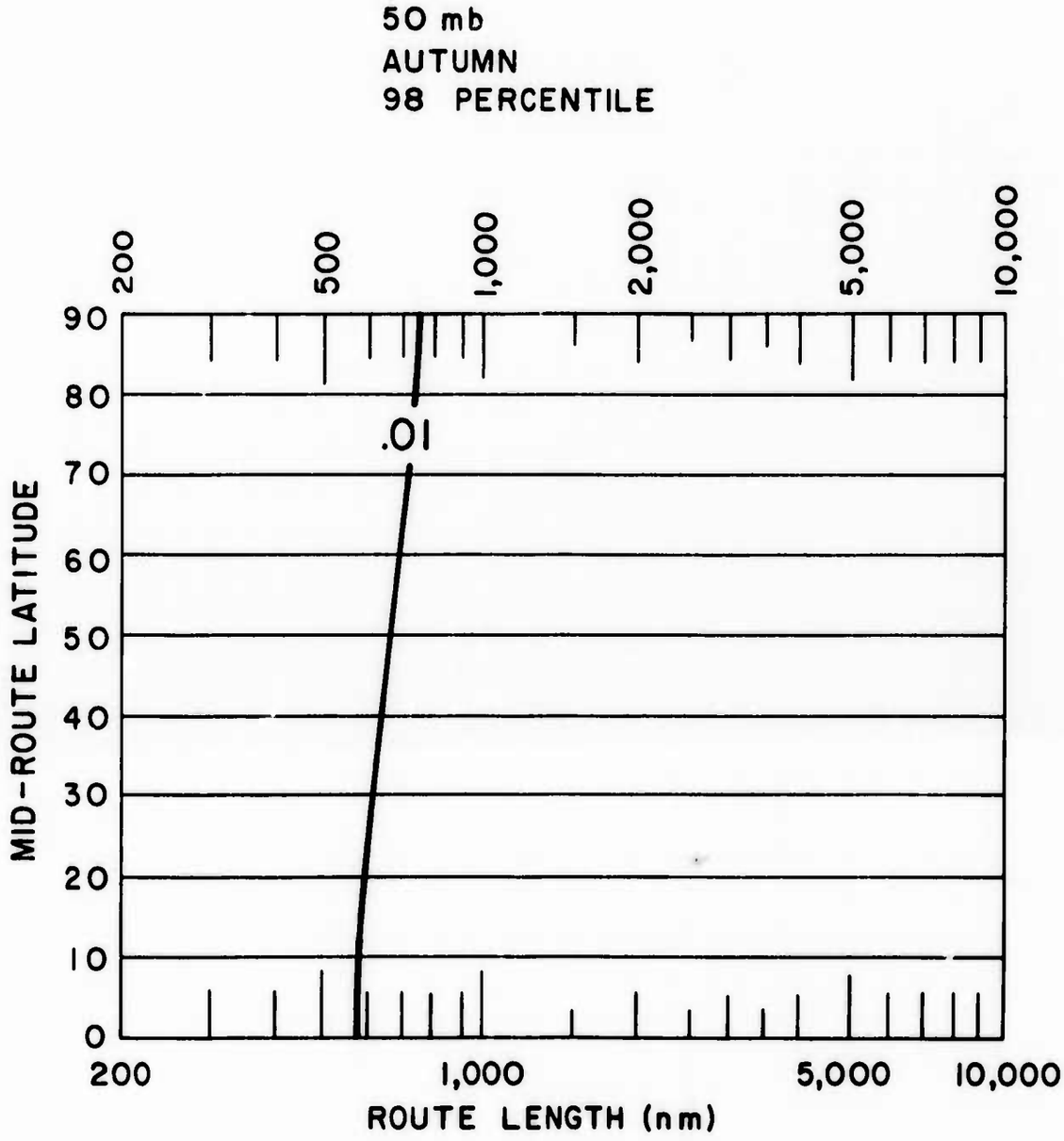


Plate 56. Temperature at 50 mb, in September, October, November, 98 Percentile



Graph 56. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

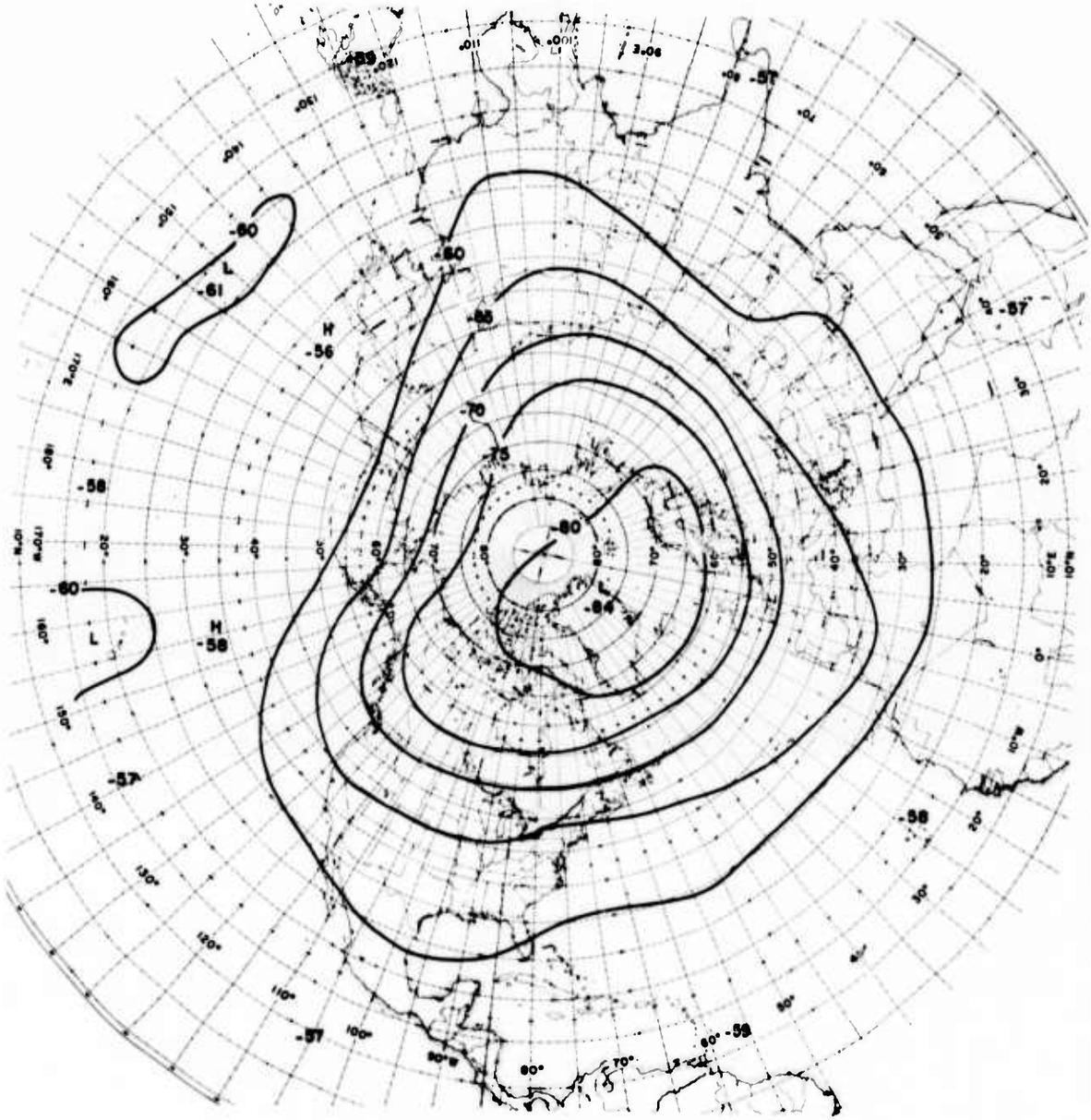
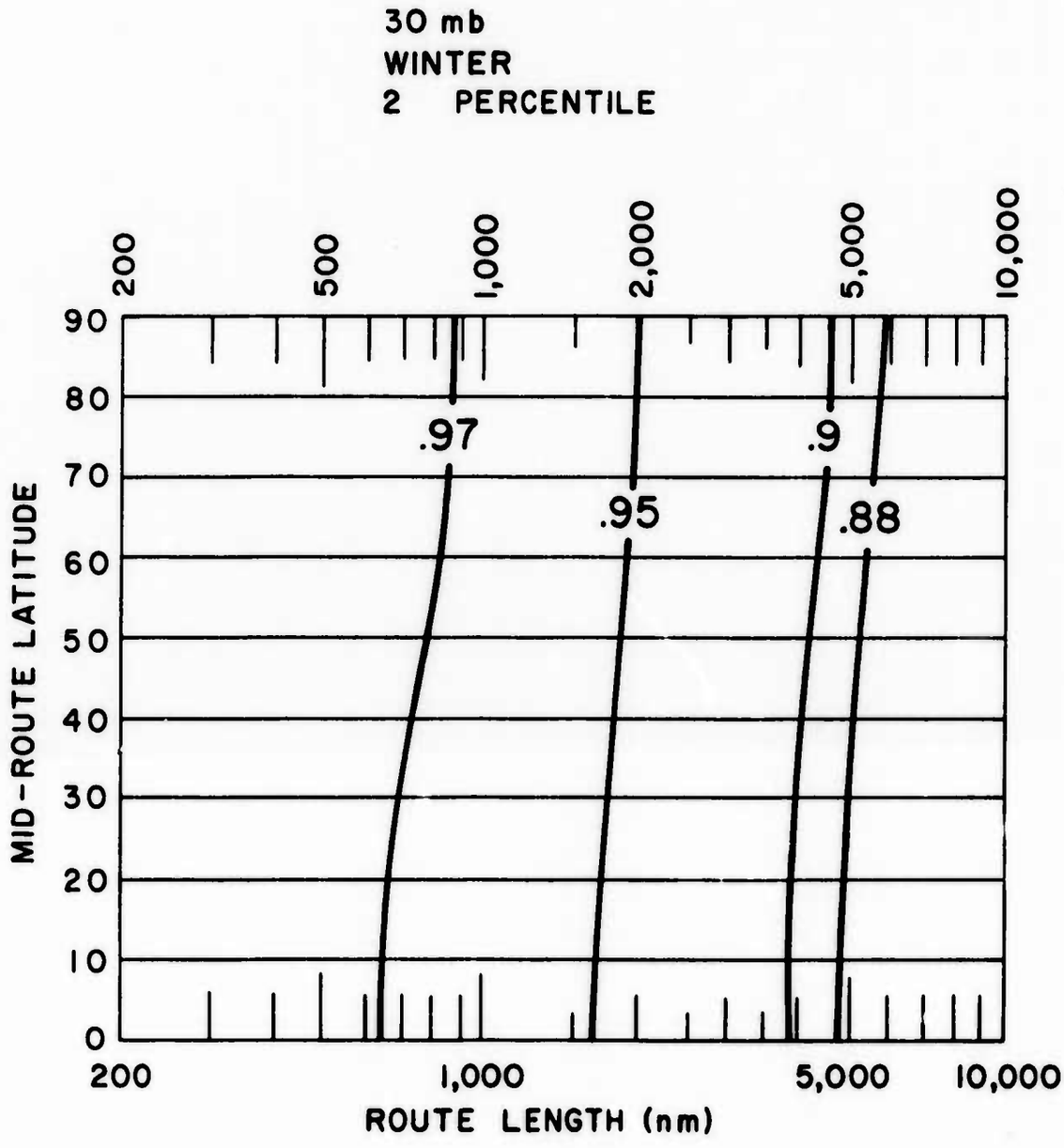


Plate 57. Temperature at 30 mb, in December, January, February, 2 Percentile



Graph 57. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

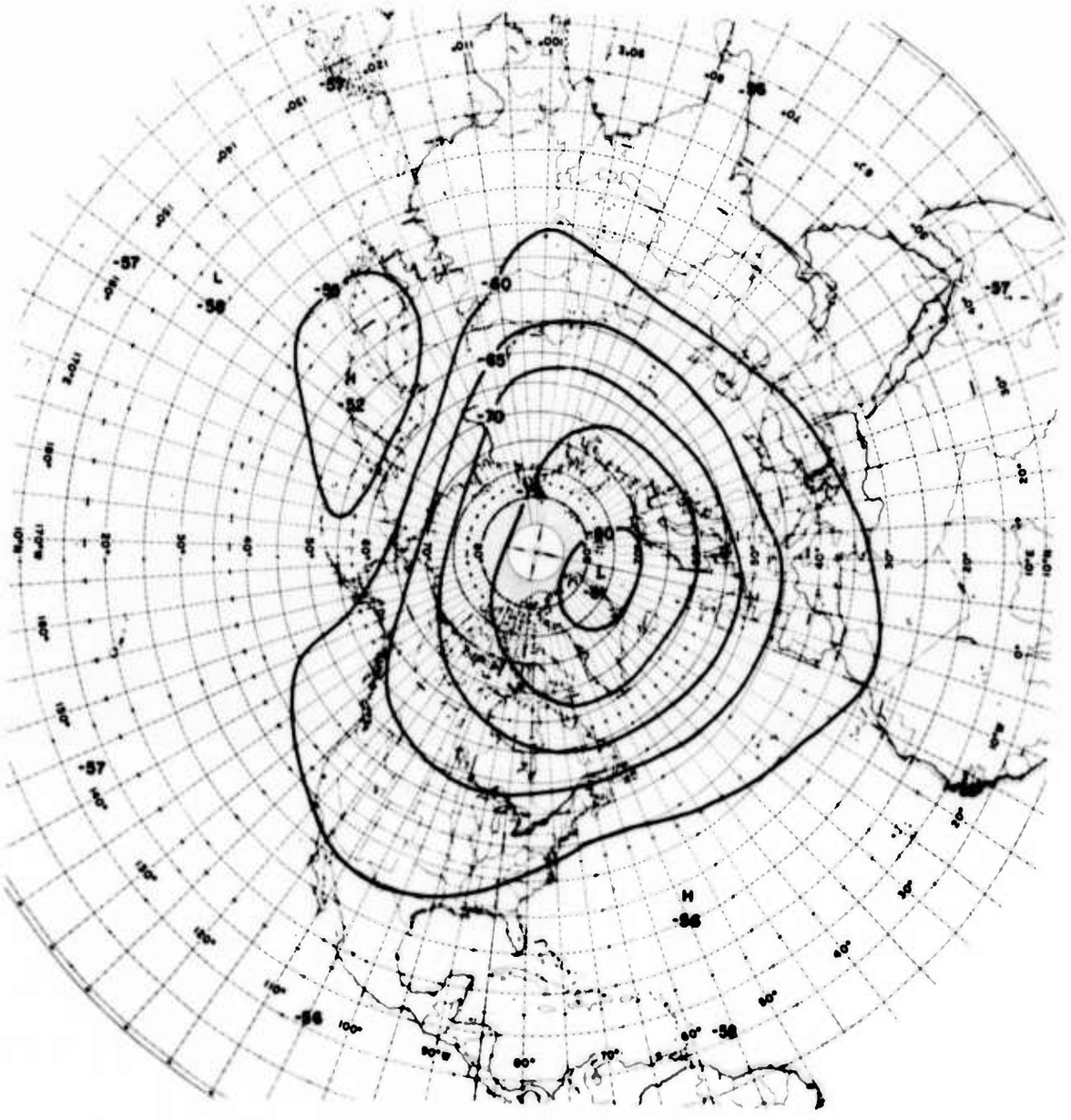
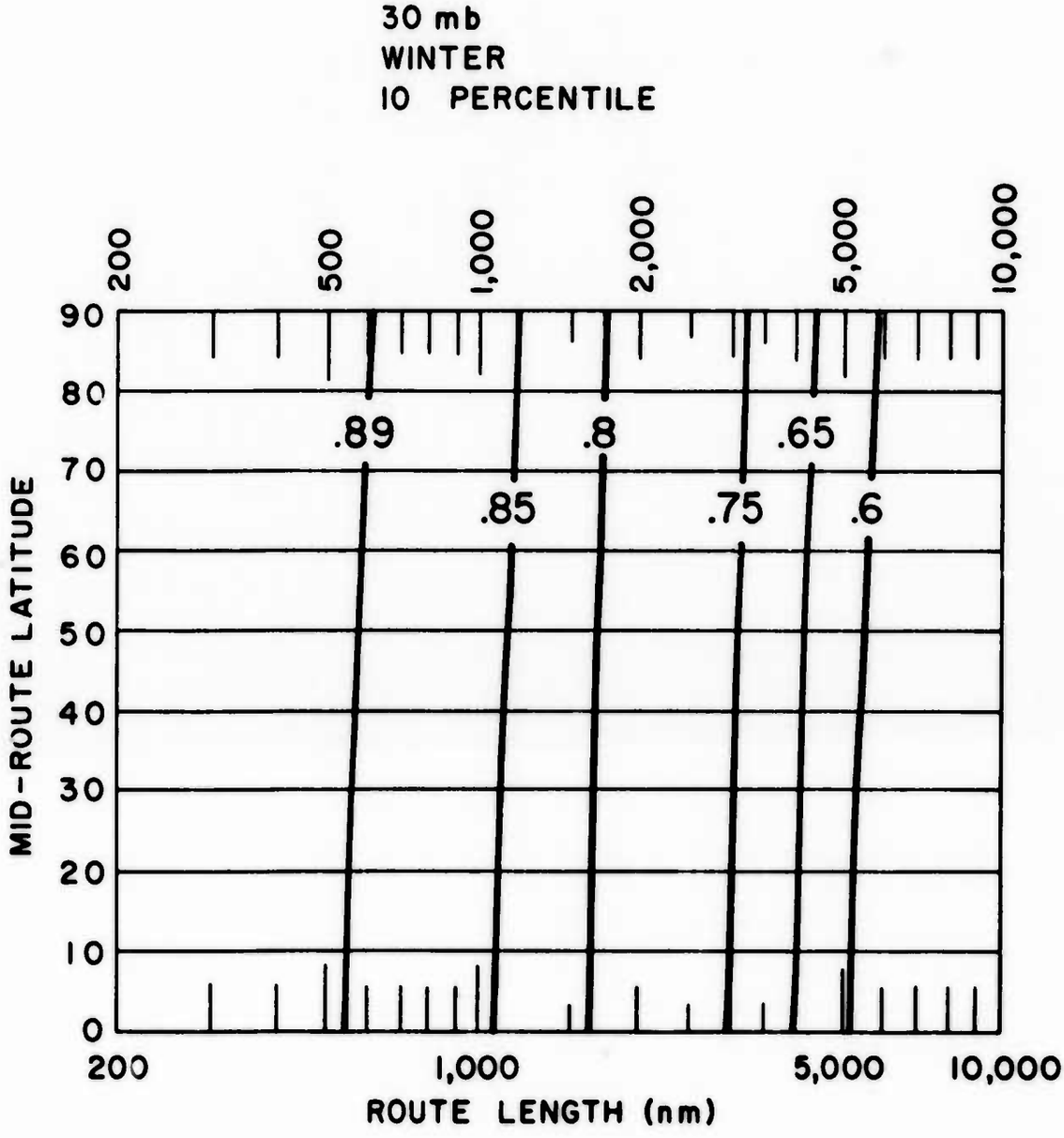


Plate 58. Temperature at 30 mb, in December, January, February, 10 Percentile



Graph 58. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

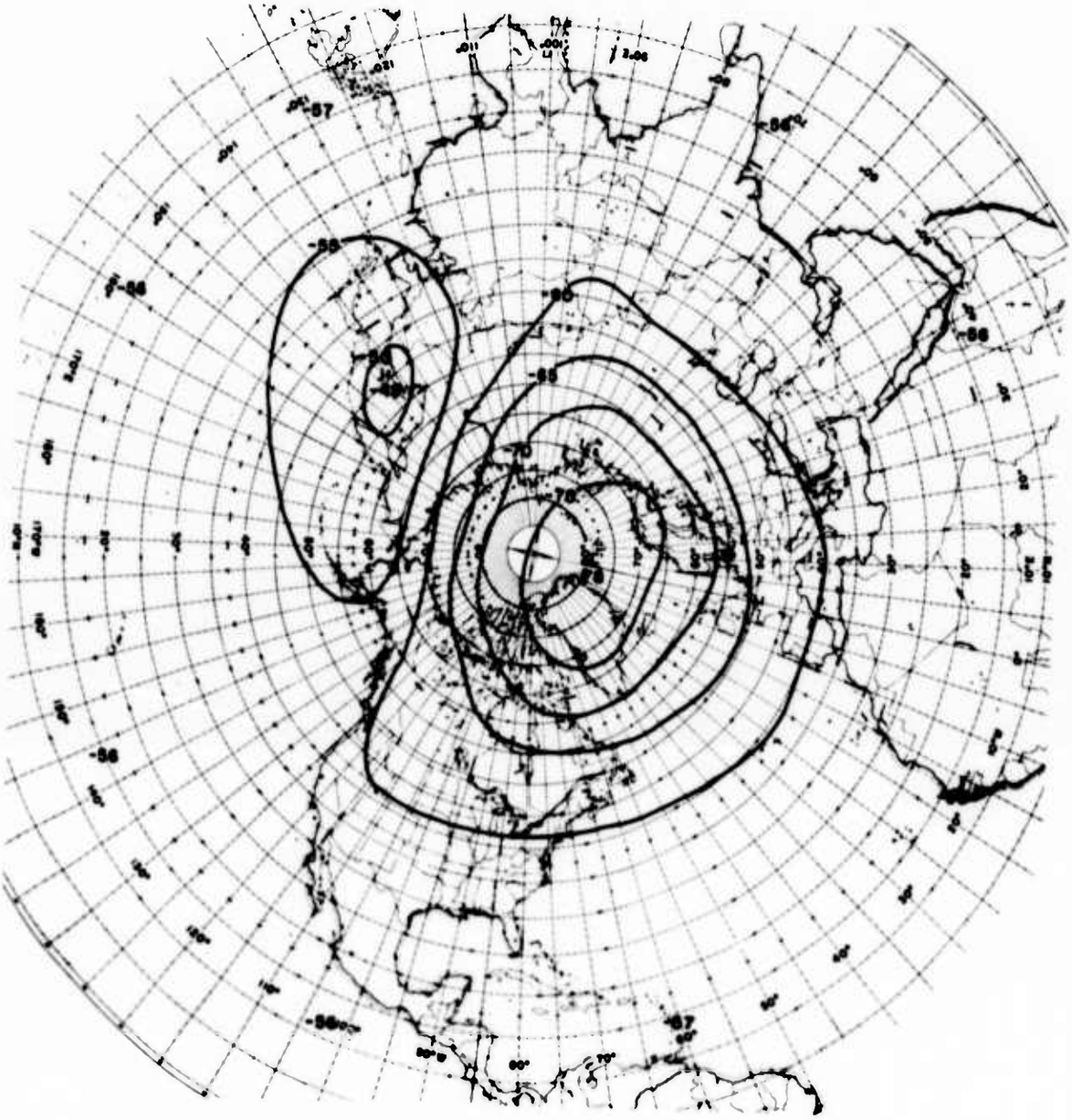
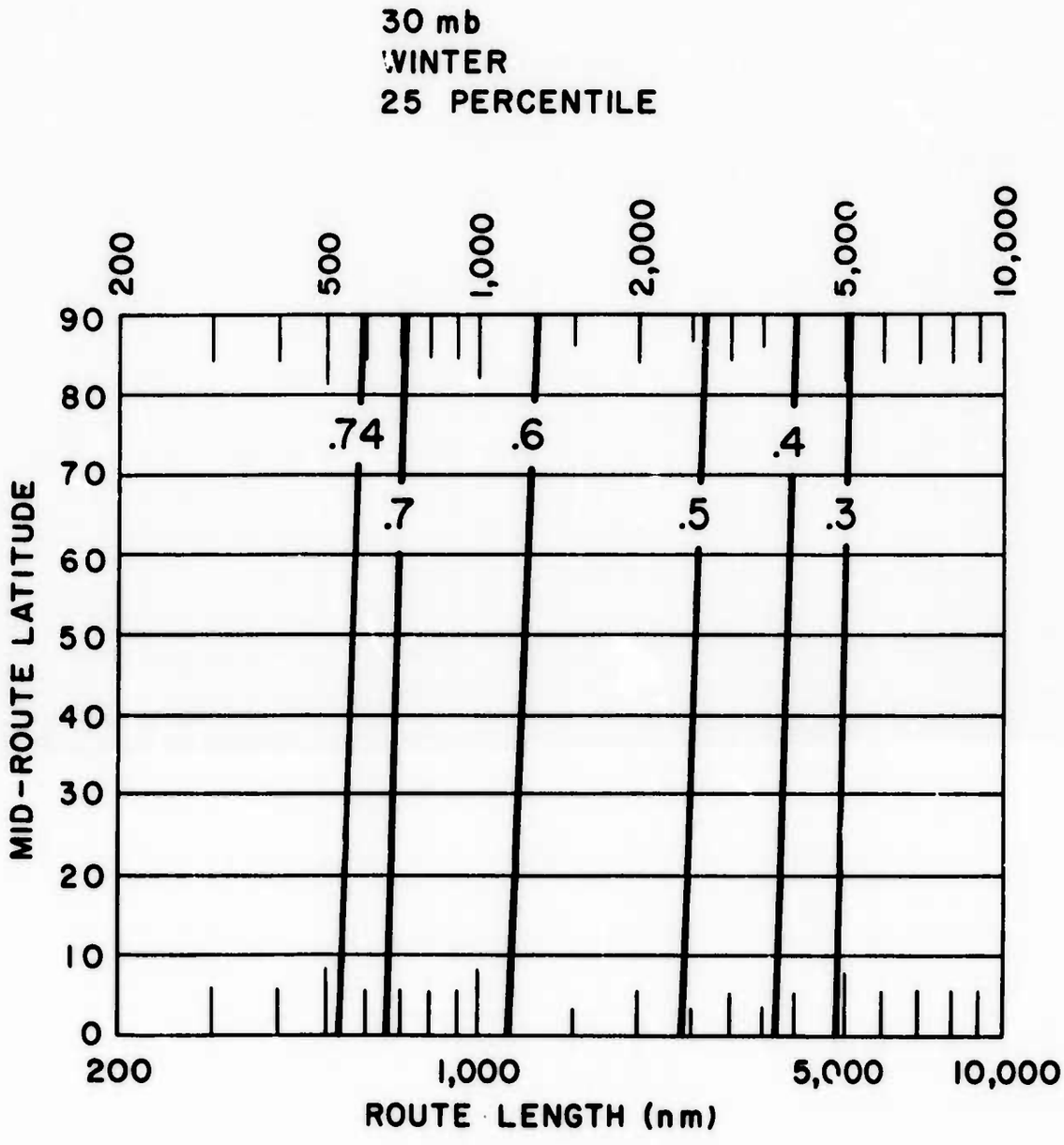


Plate 59. Temperature at 30 mb, in December, January, February, 25 Percentile



Graph 59. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

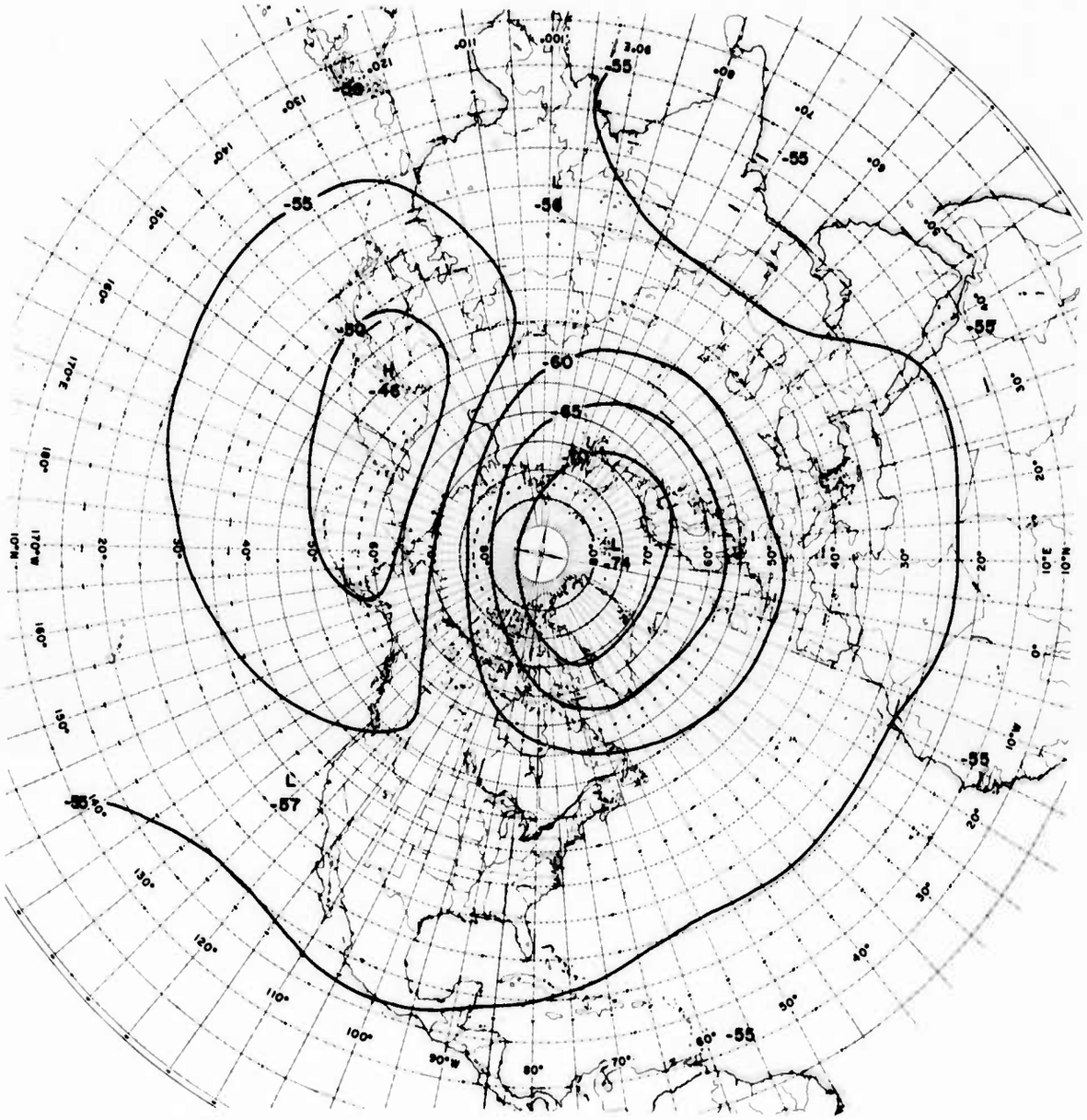
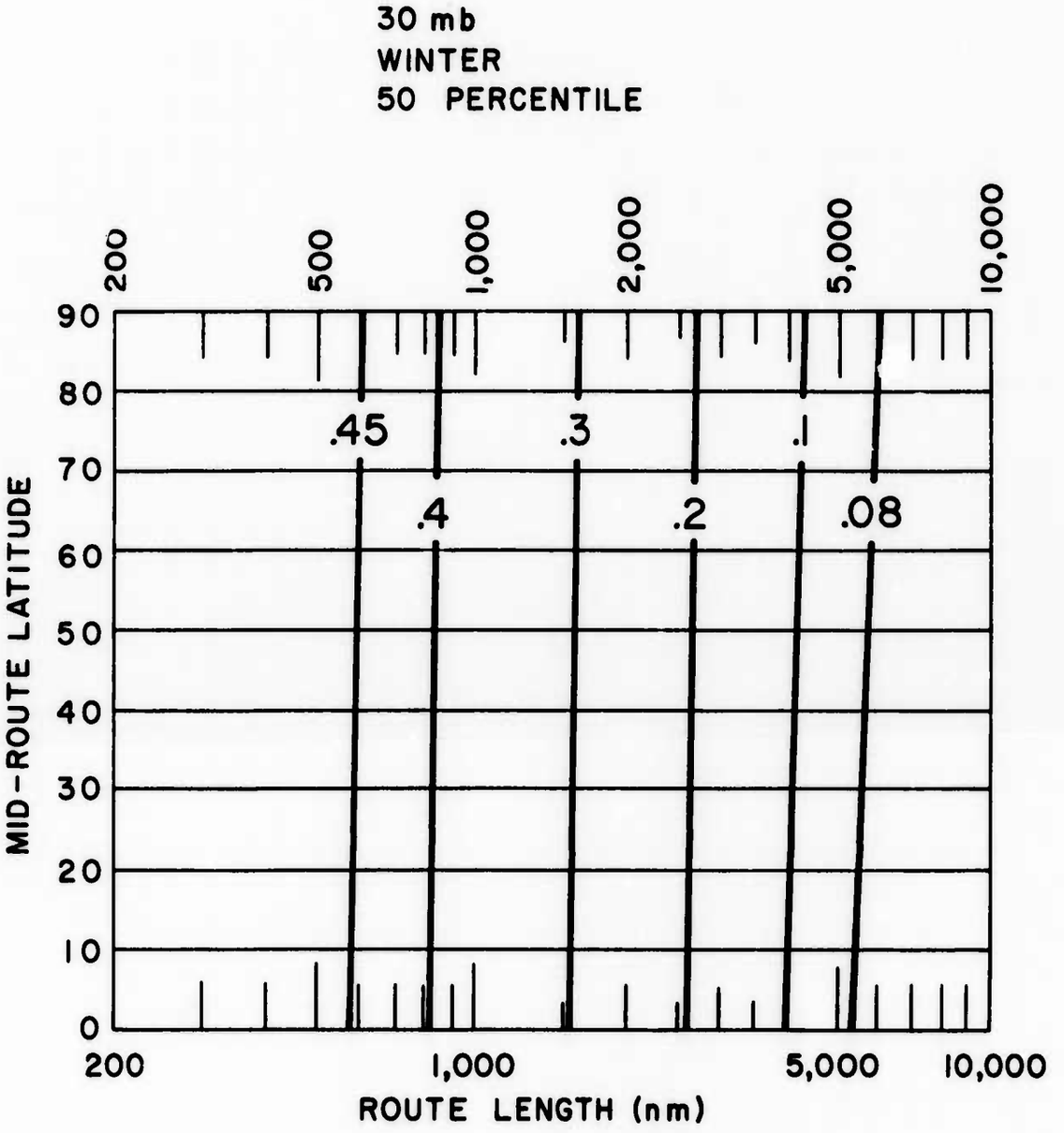


Plate 60. Temperature at 30 mb, in December, January, February, 50 Percentile



Graph 60. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

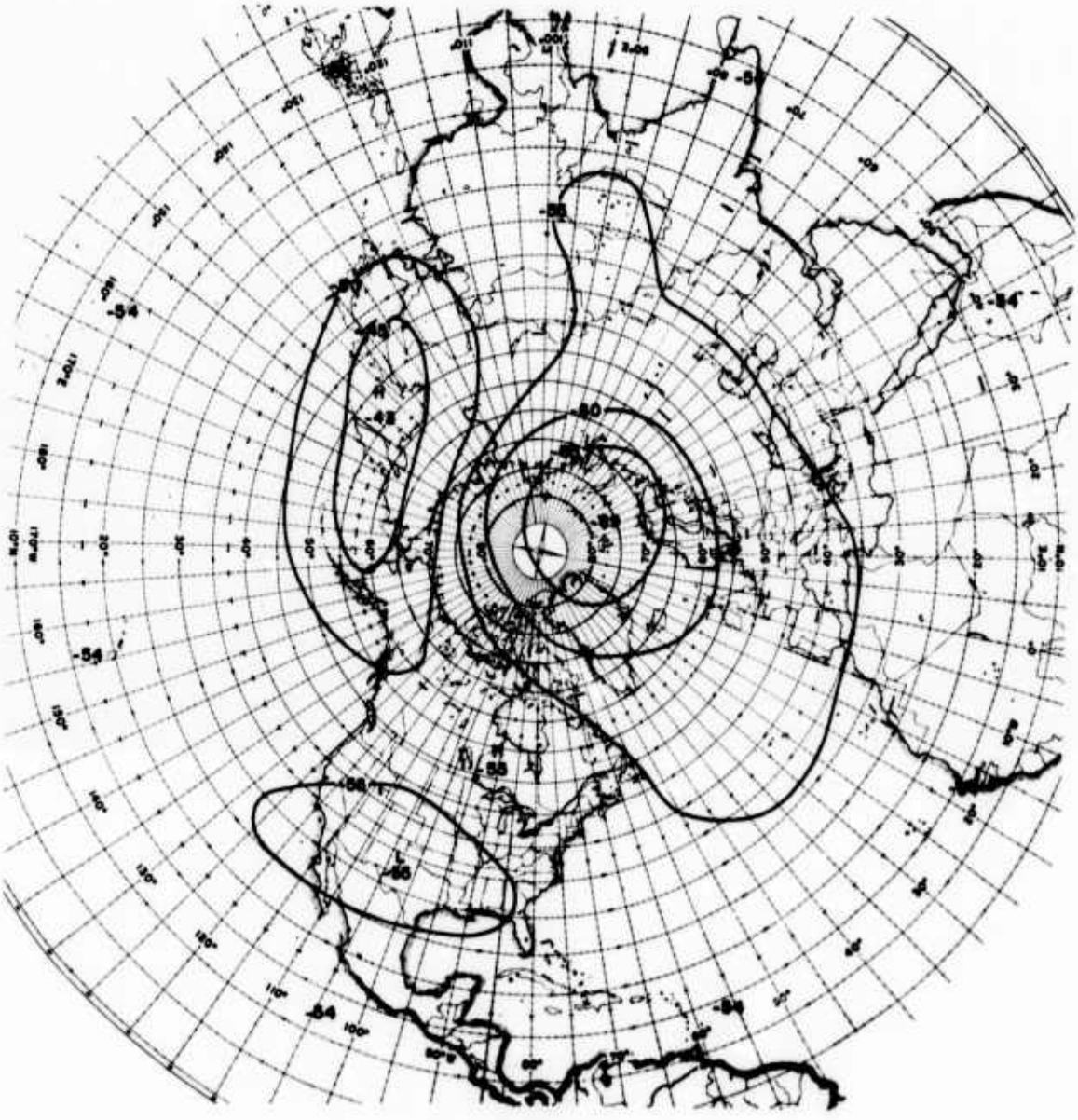
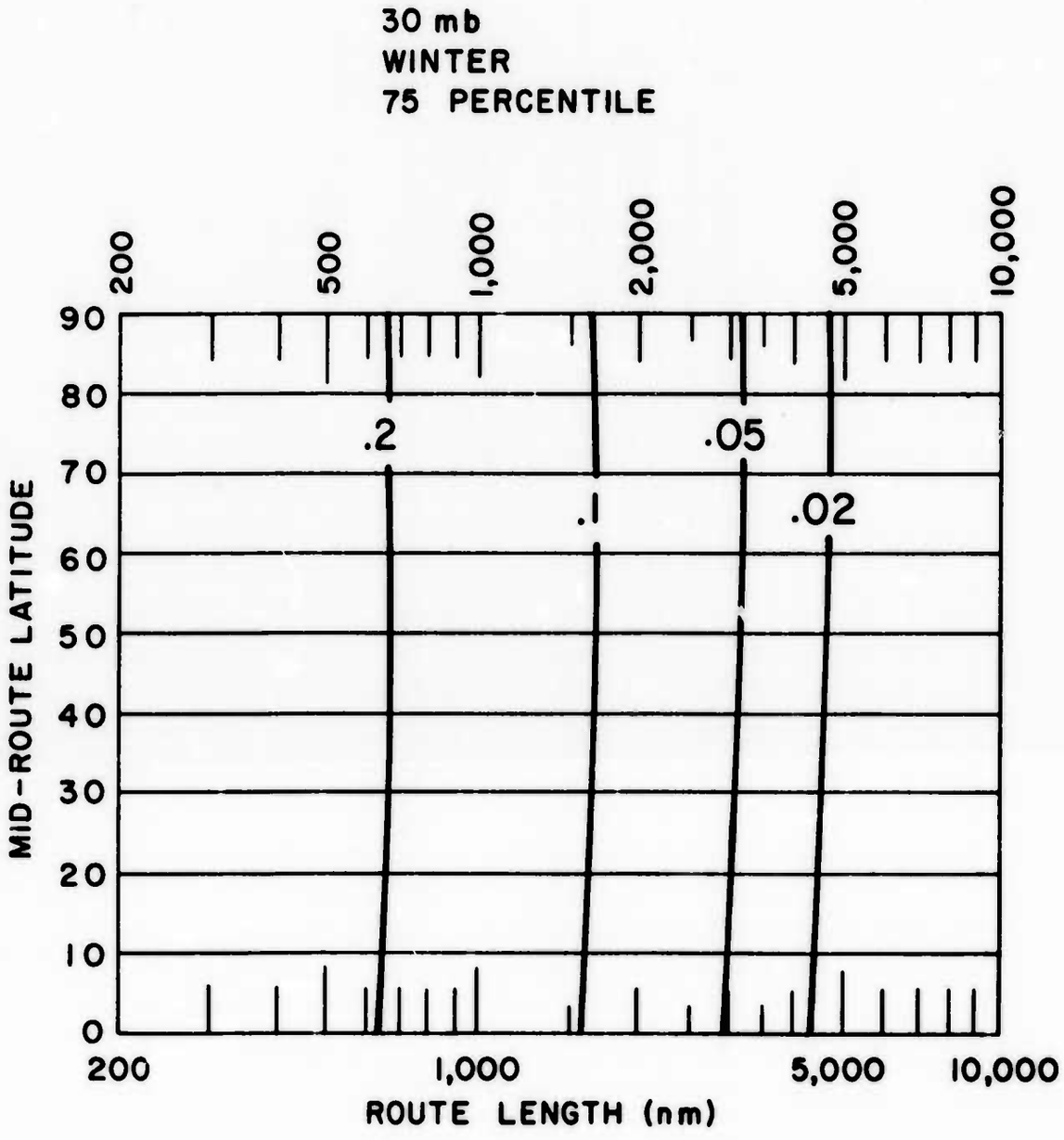


Plate 61. Temperature at 30 mb, in December, January, February, 75 Percentile



Graph 61. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

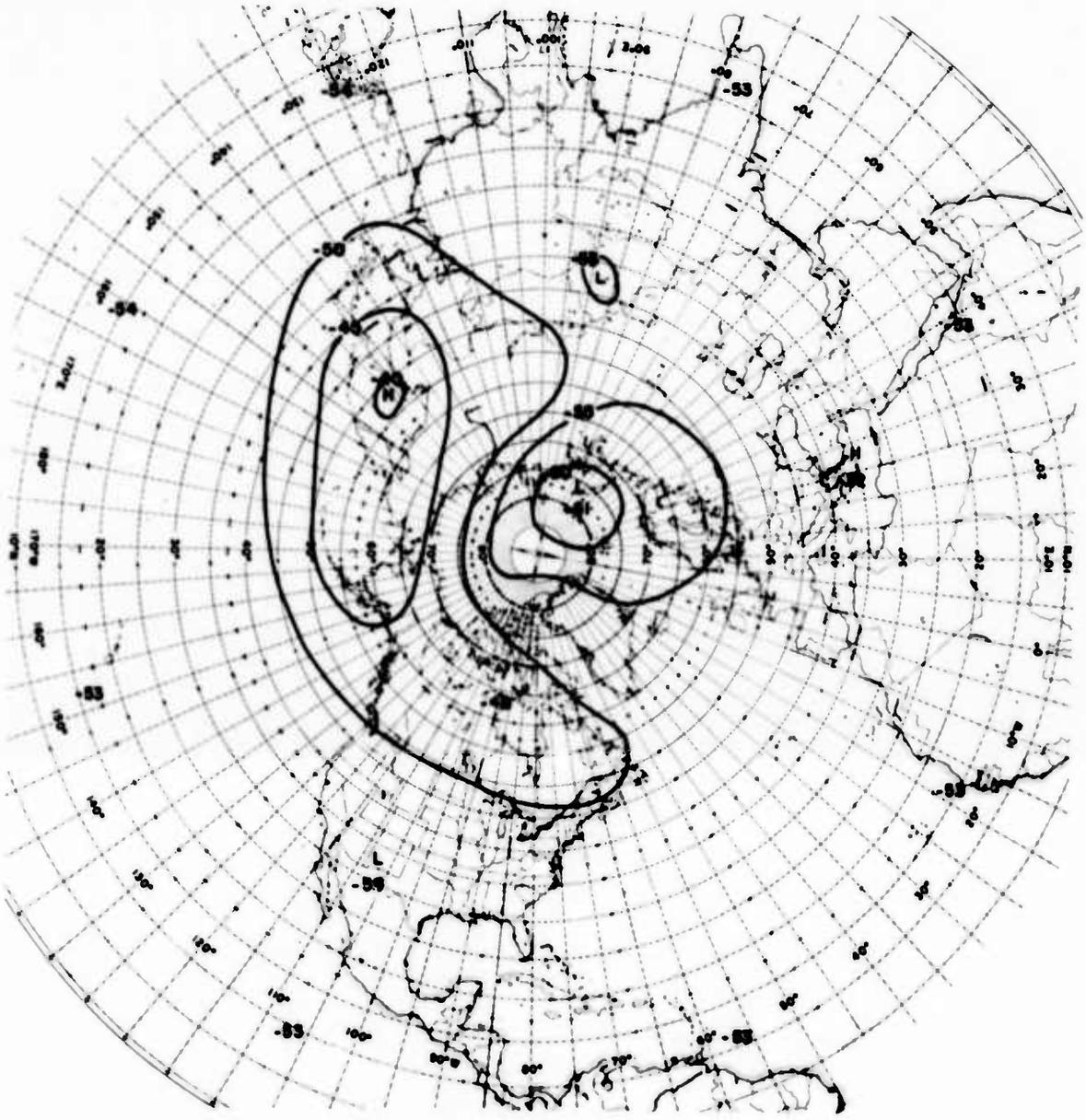
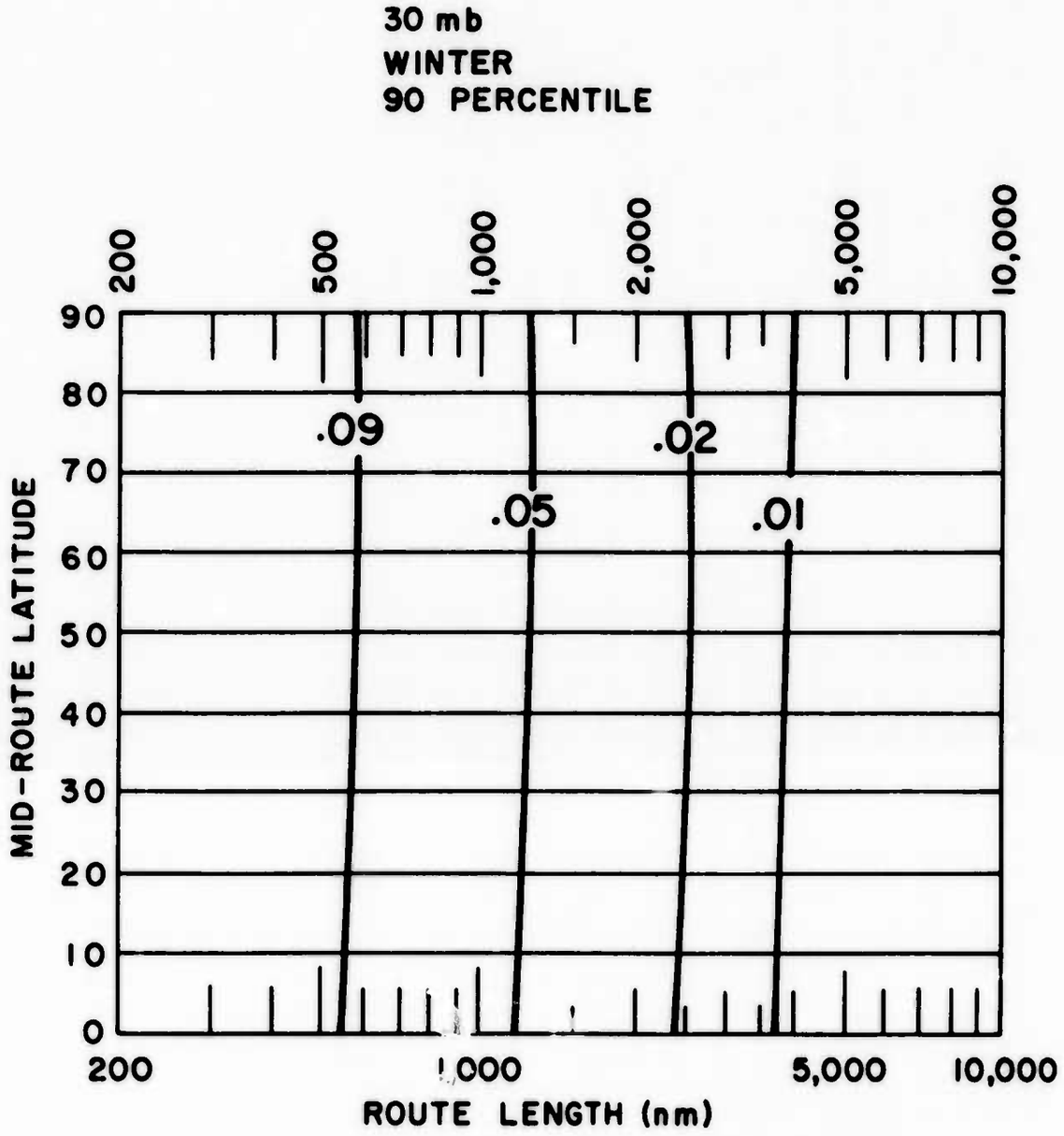


Plate 62. Temperature at 30 mb, in December, January, February, 90 Percentile



Graph 62. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

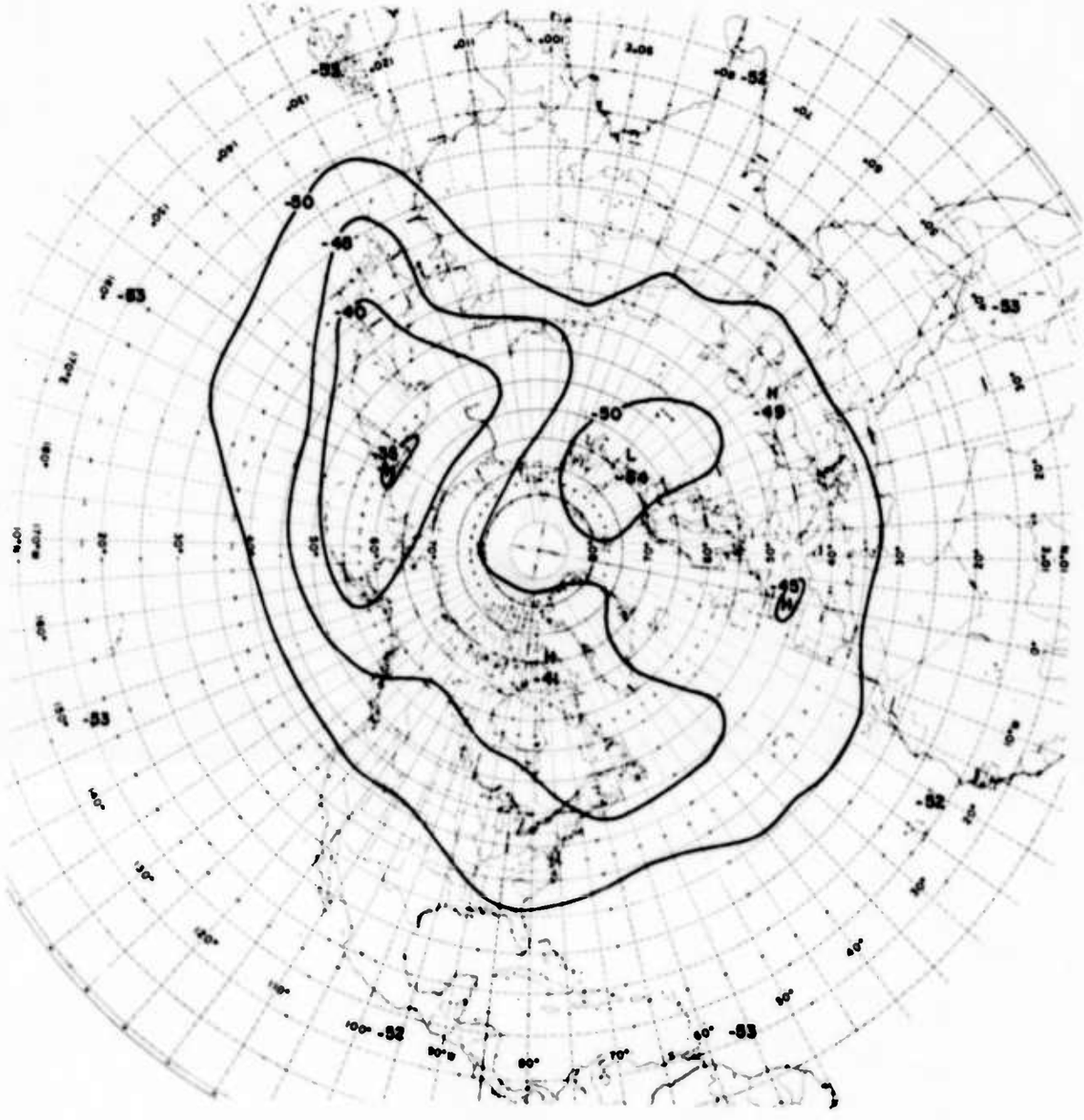
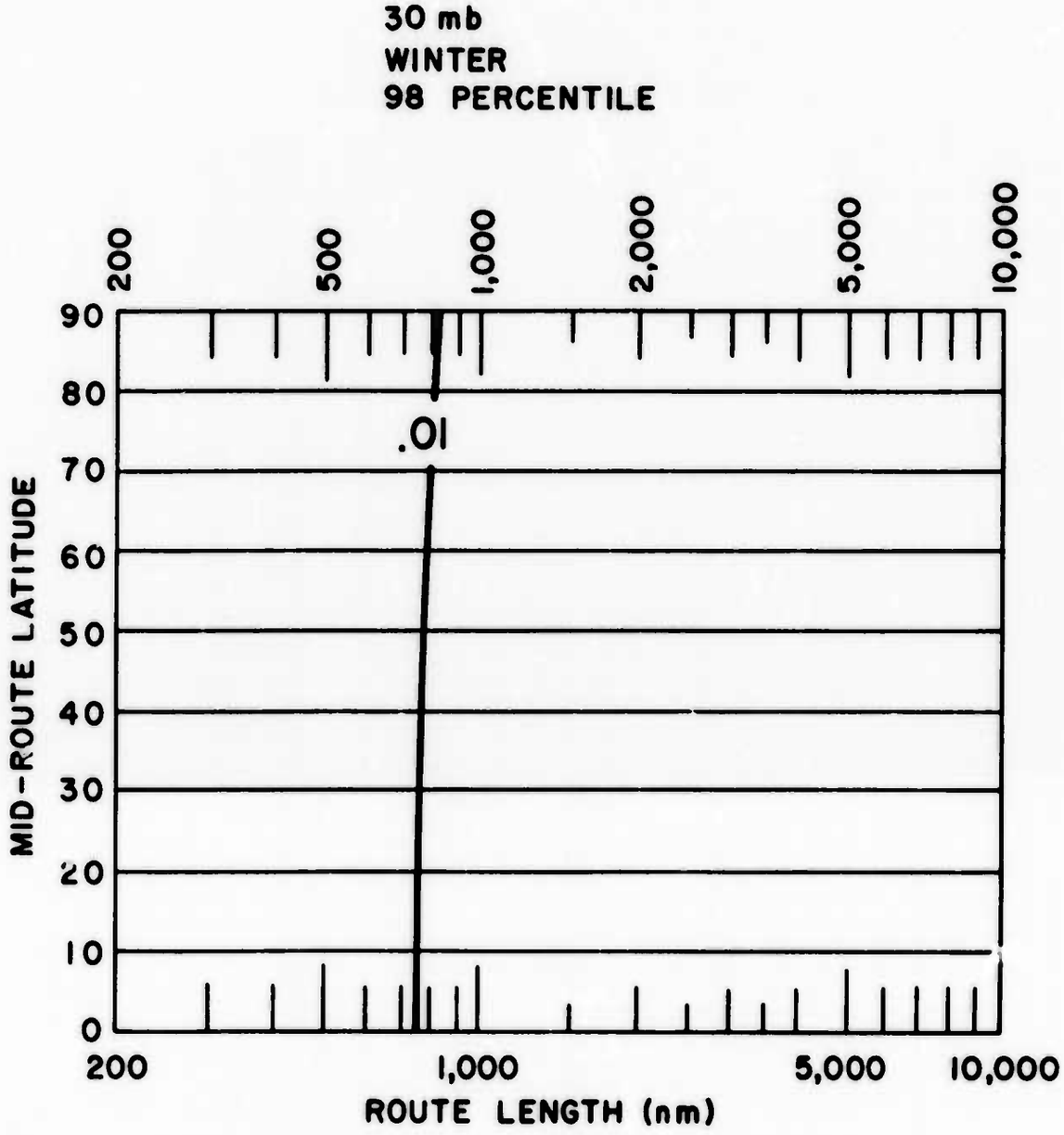


Plate 63. Temperature at 30 mb, in December, January, February, 98 Percentile



Graph 63. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

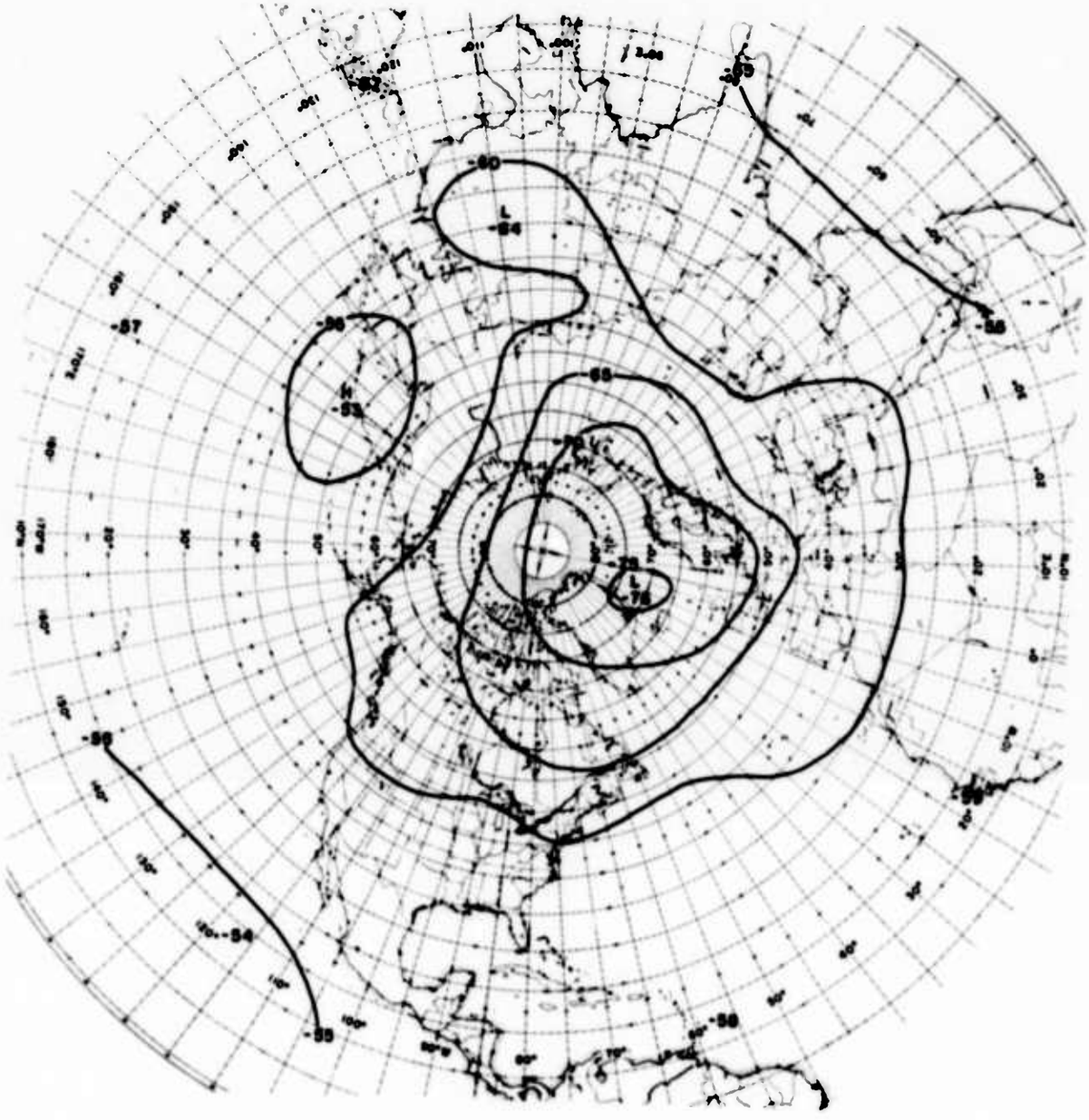
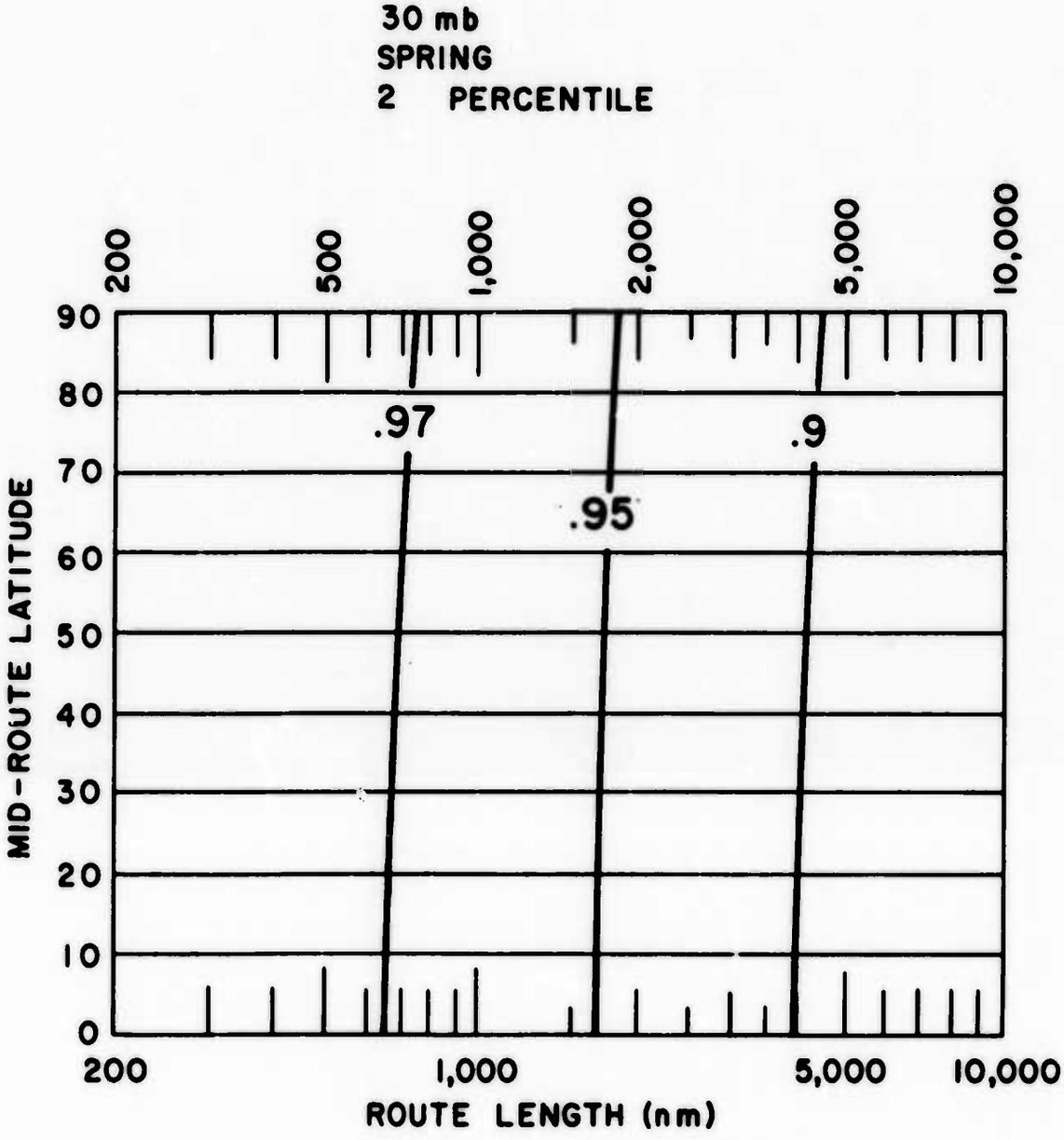


Plate 64. Temperature at 30 mb, in March, April, May, 2 Percentile



Graph 64. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

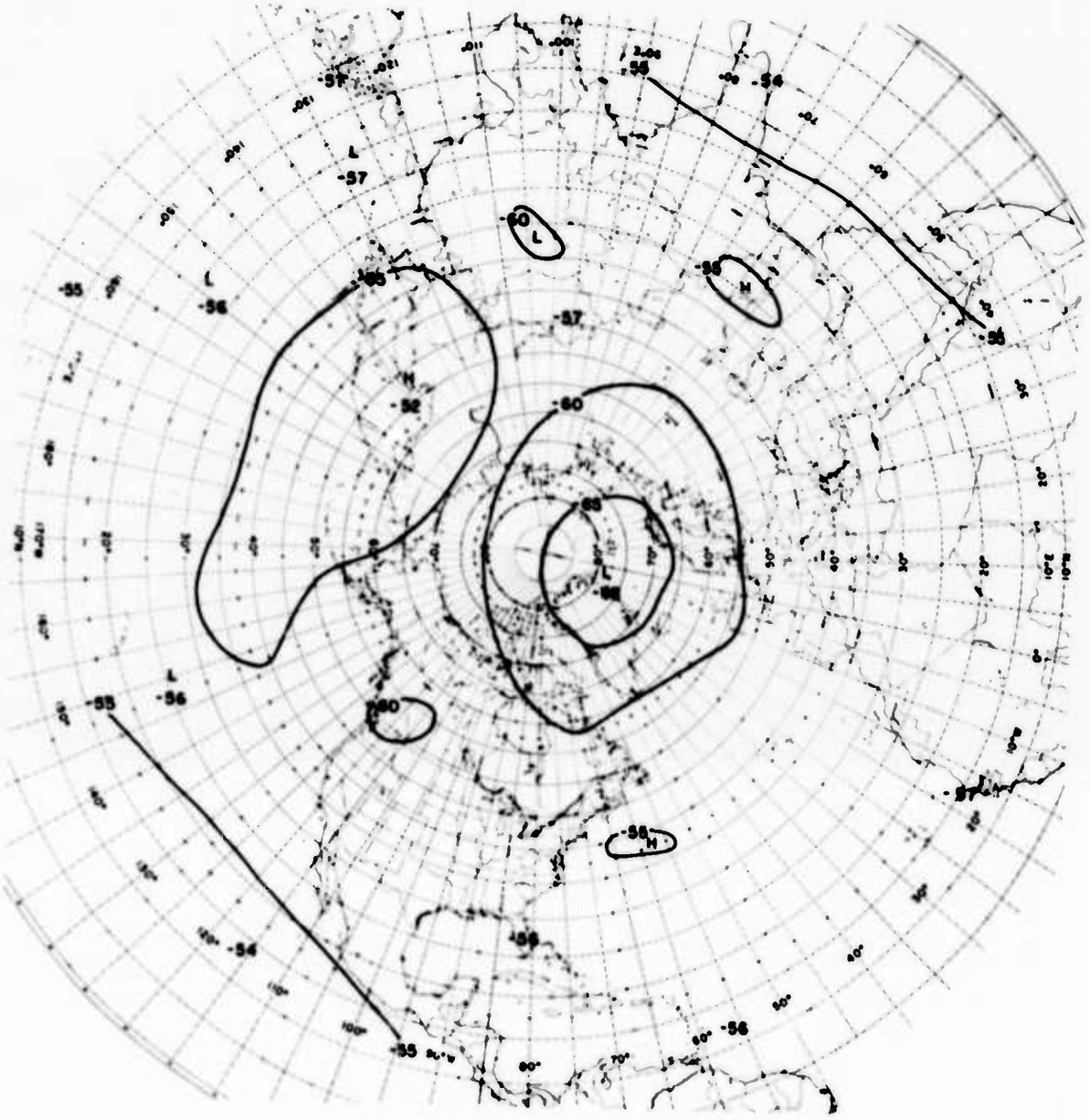
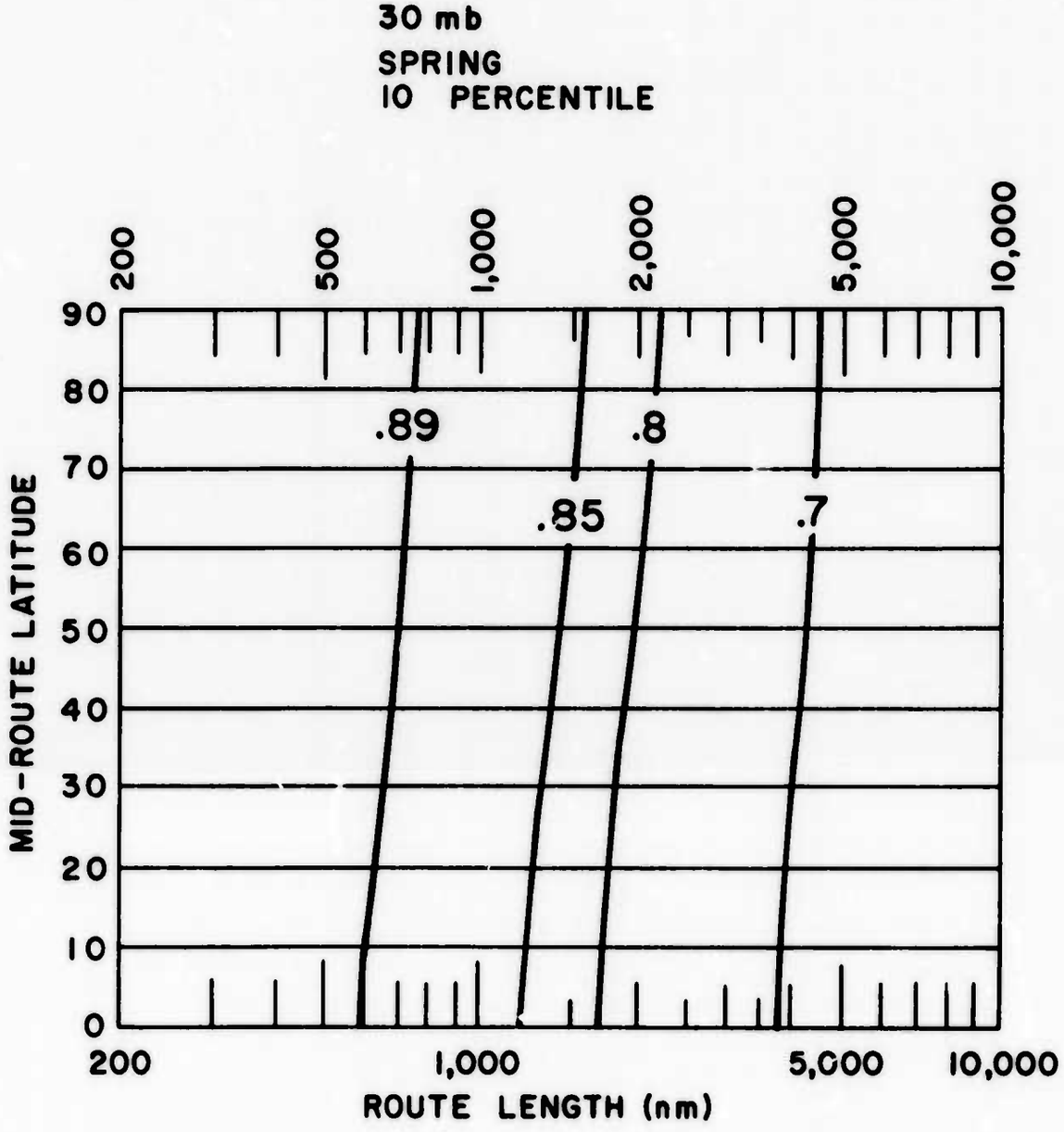


Plate 65. Temperature at 30 mb, in March, April, May, 10 Percentile



Graph 65. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

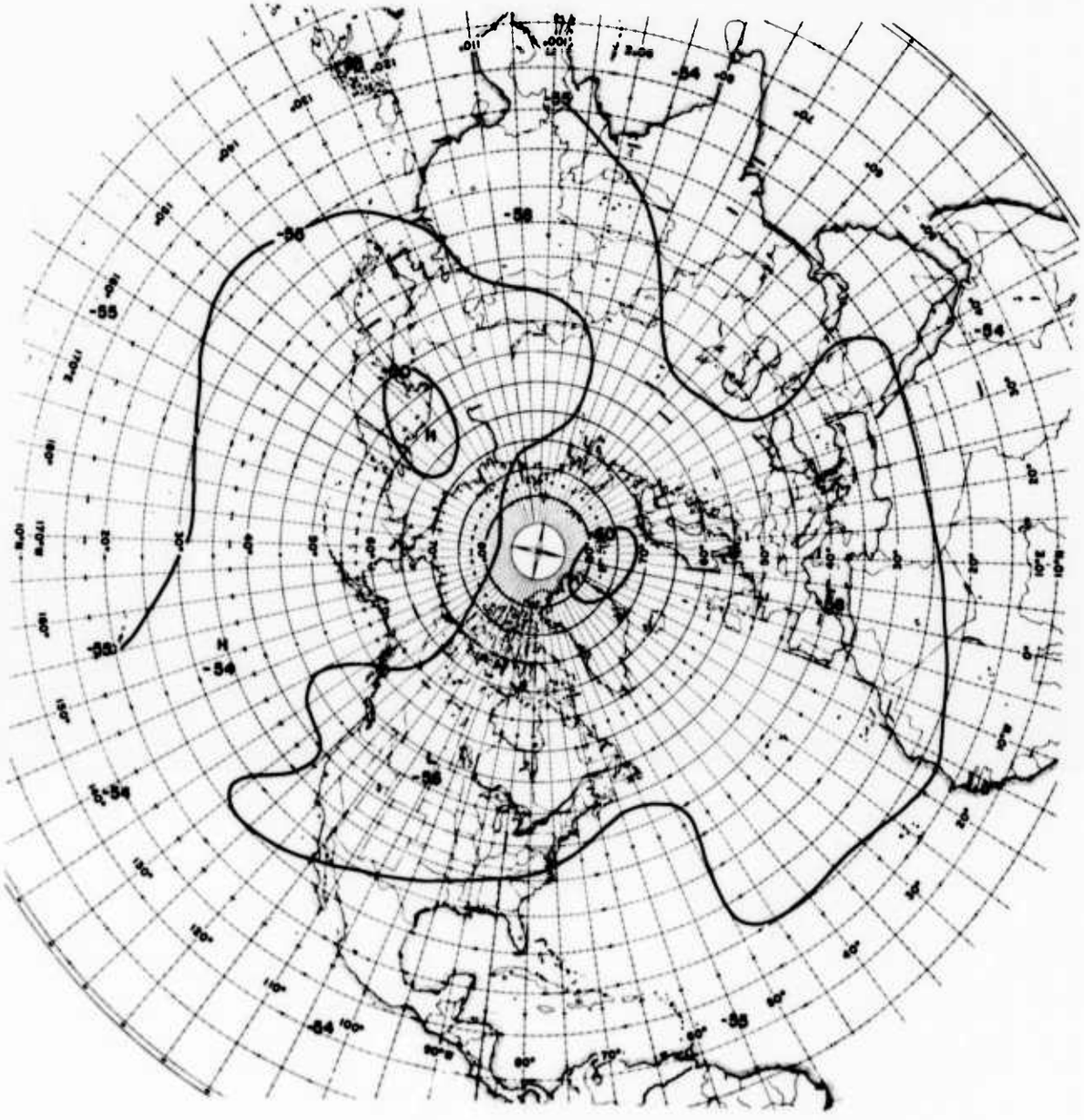
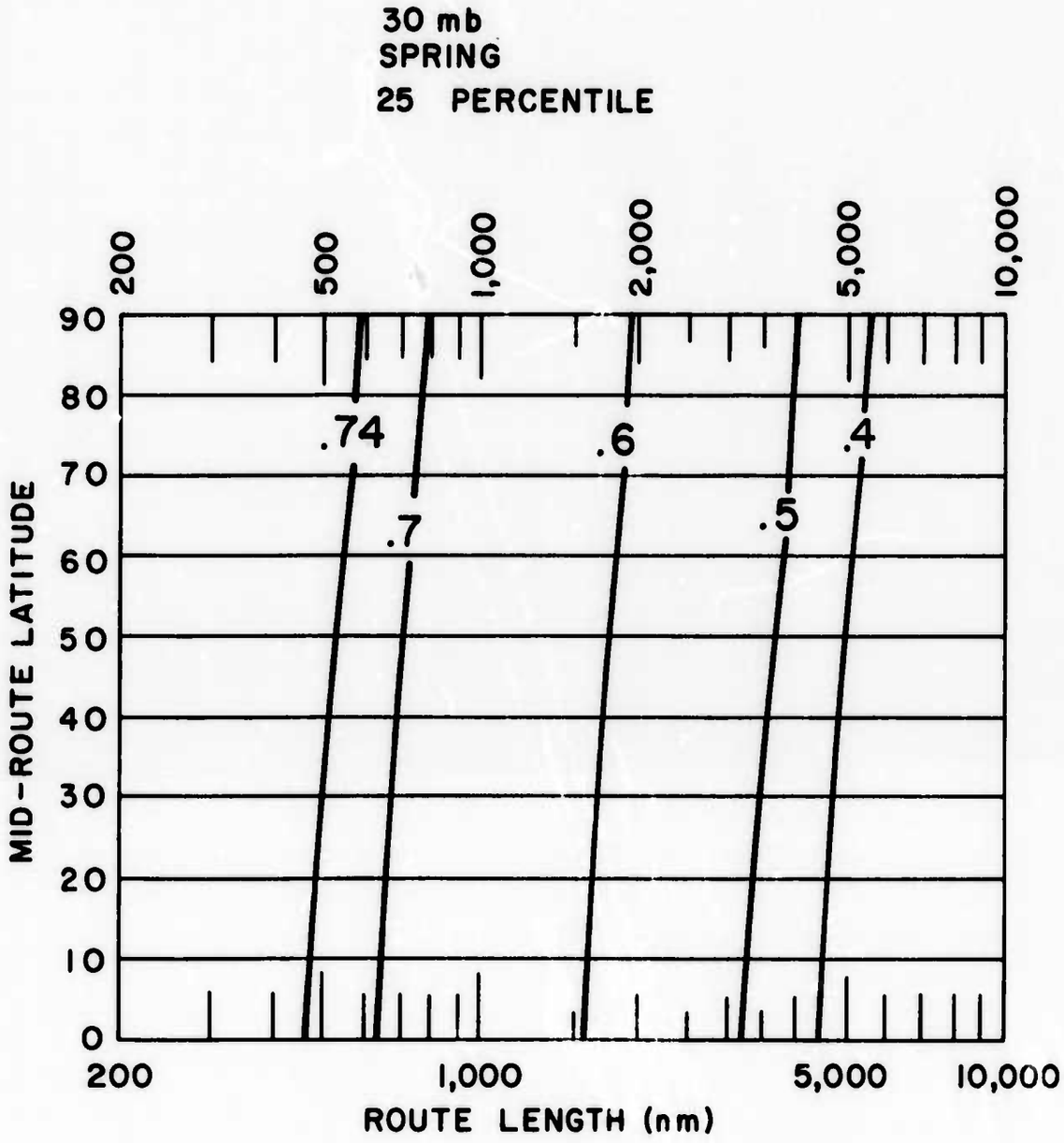


Plate 66. Temperature at 30 mb, in March, April, May, 25 Percentile



Graph 66. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

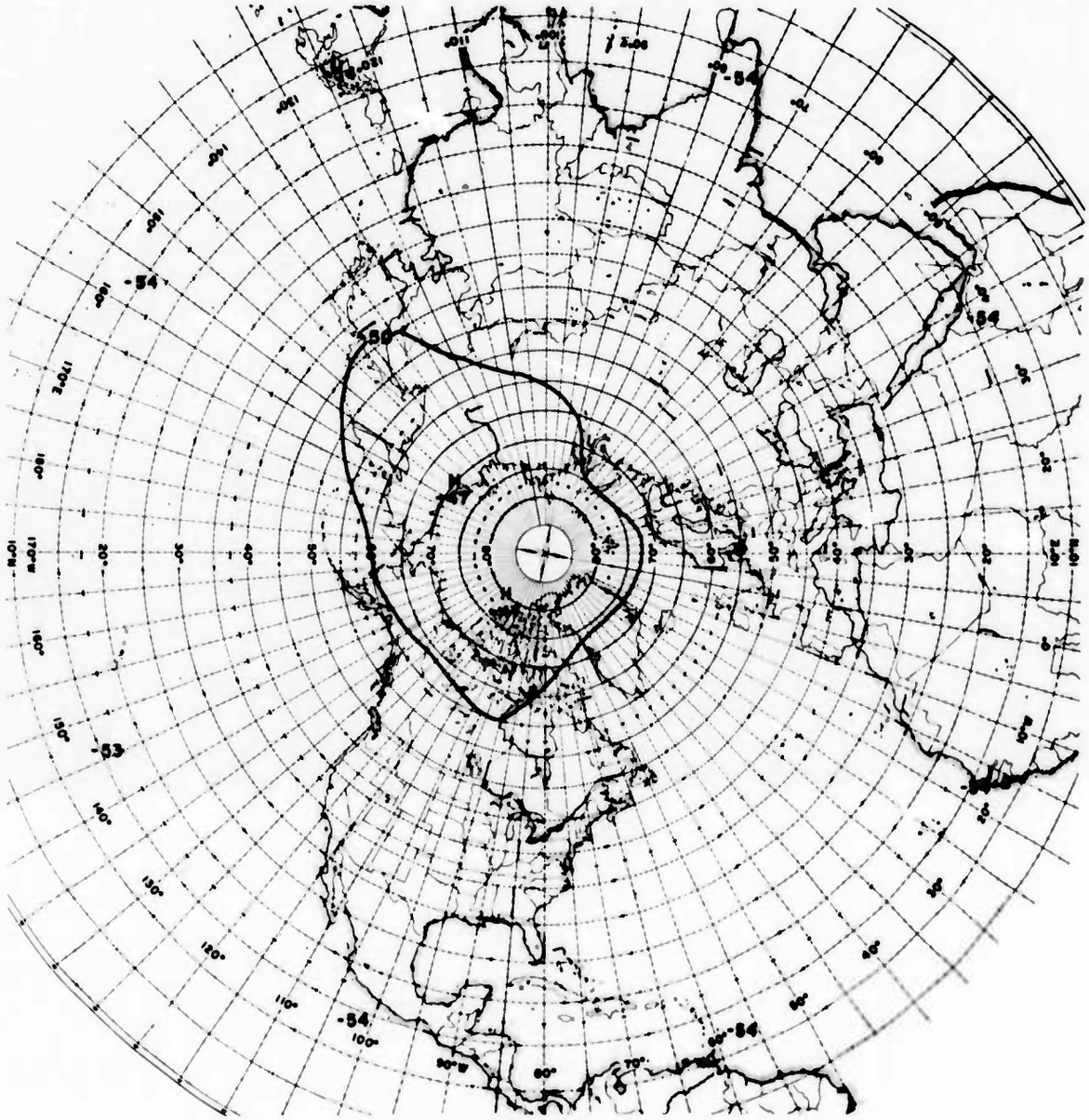
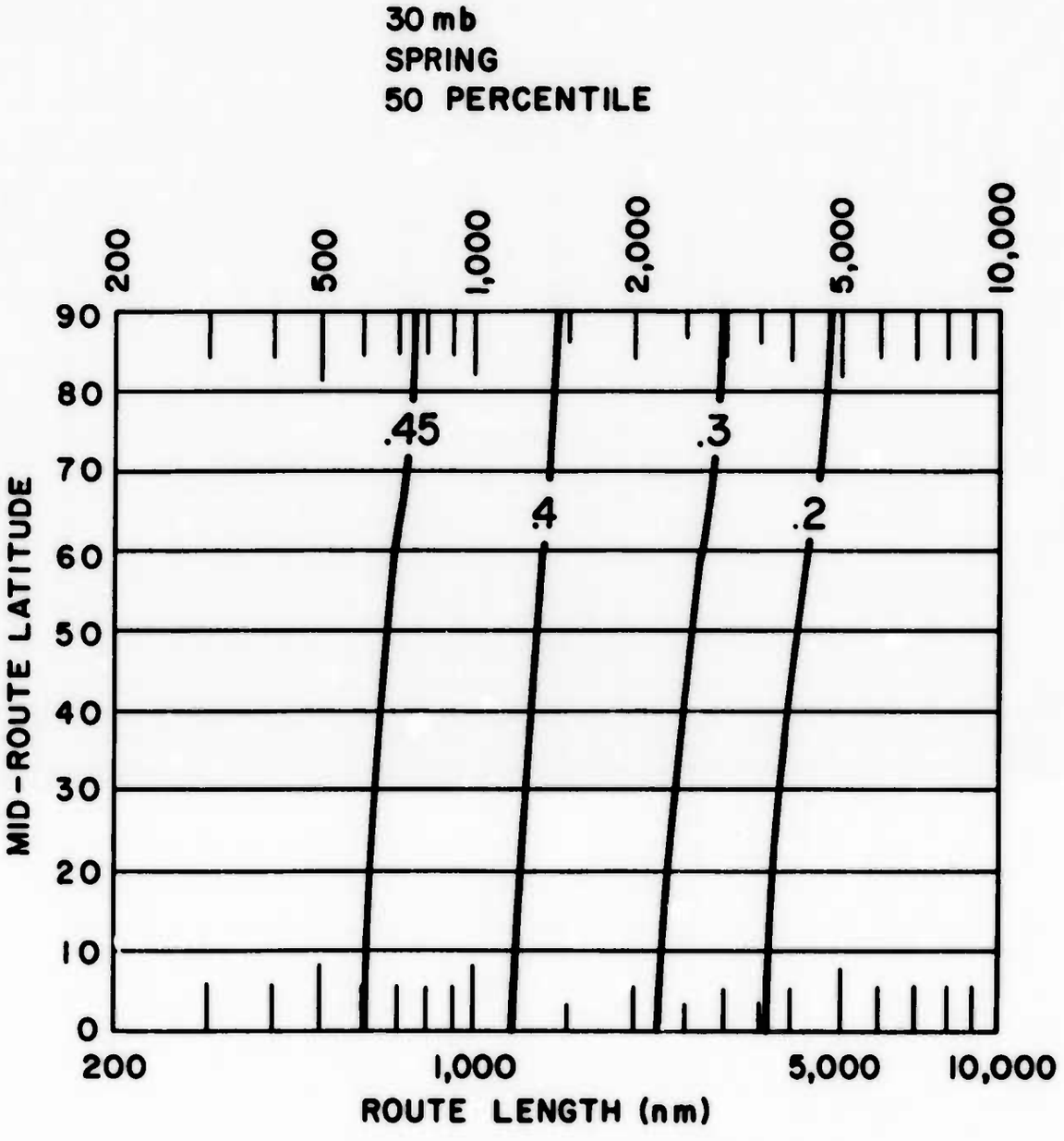


Plate 67. Temperature at 30 mb, in March, April, May, 50 Percentile



Graph 67. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

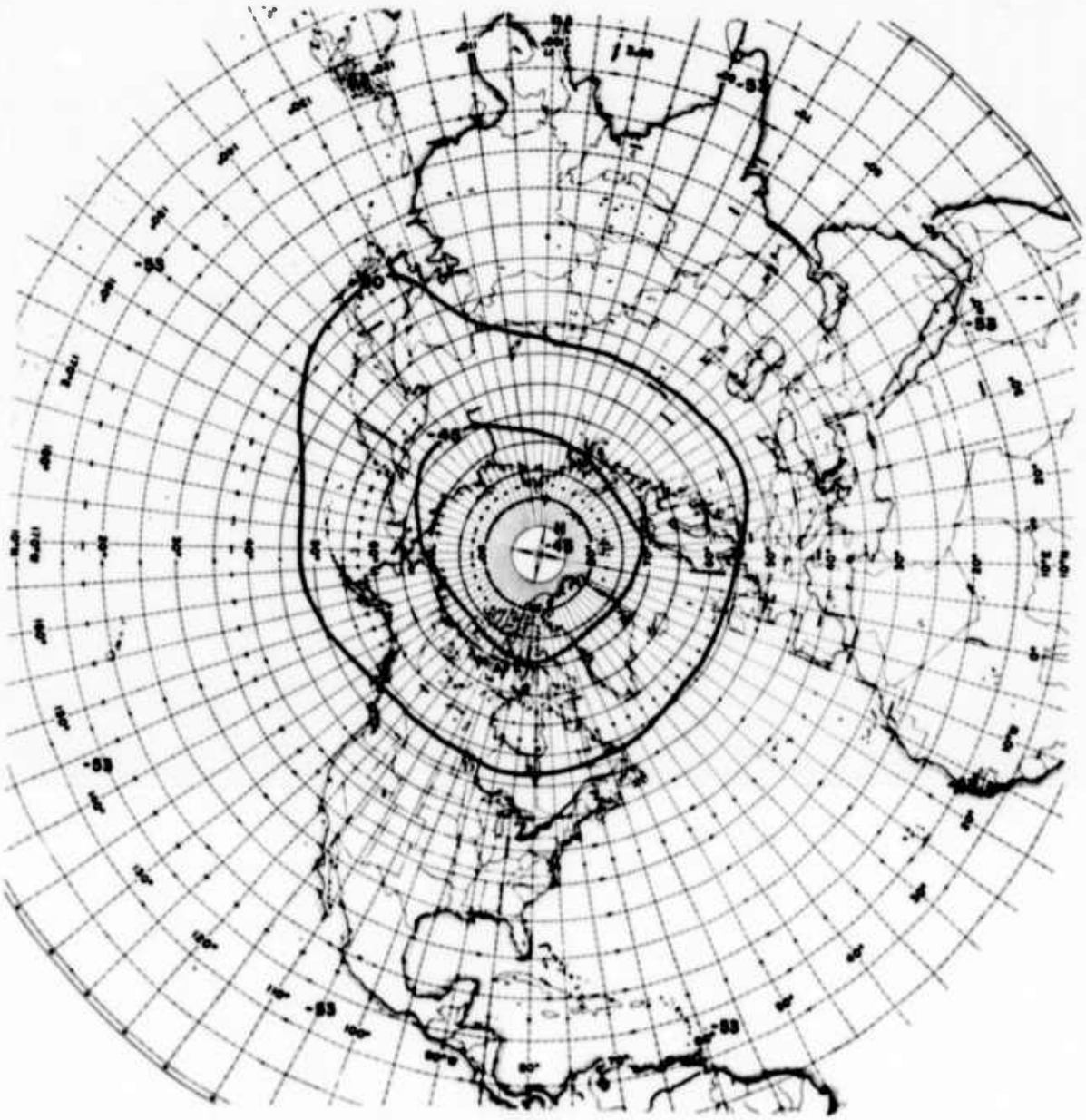
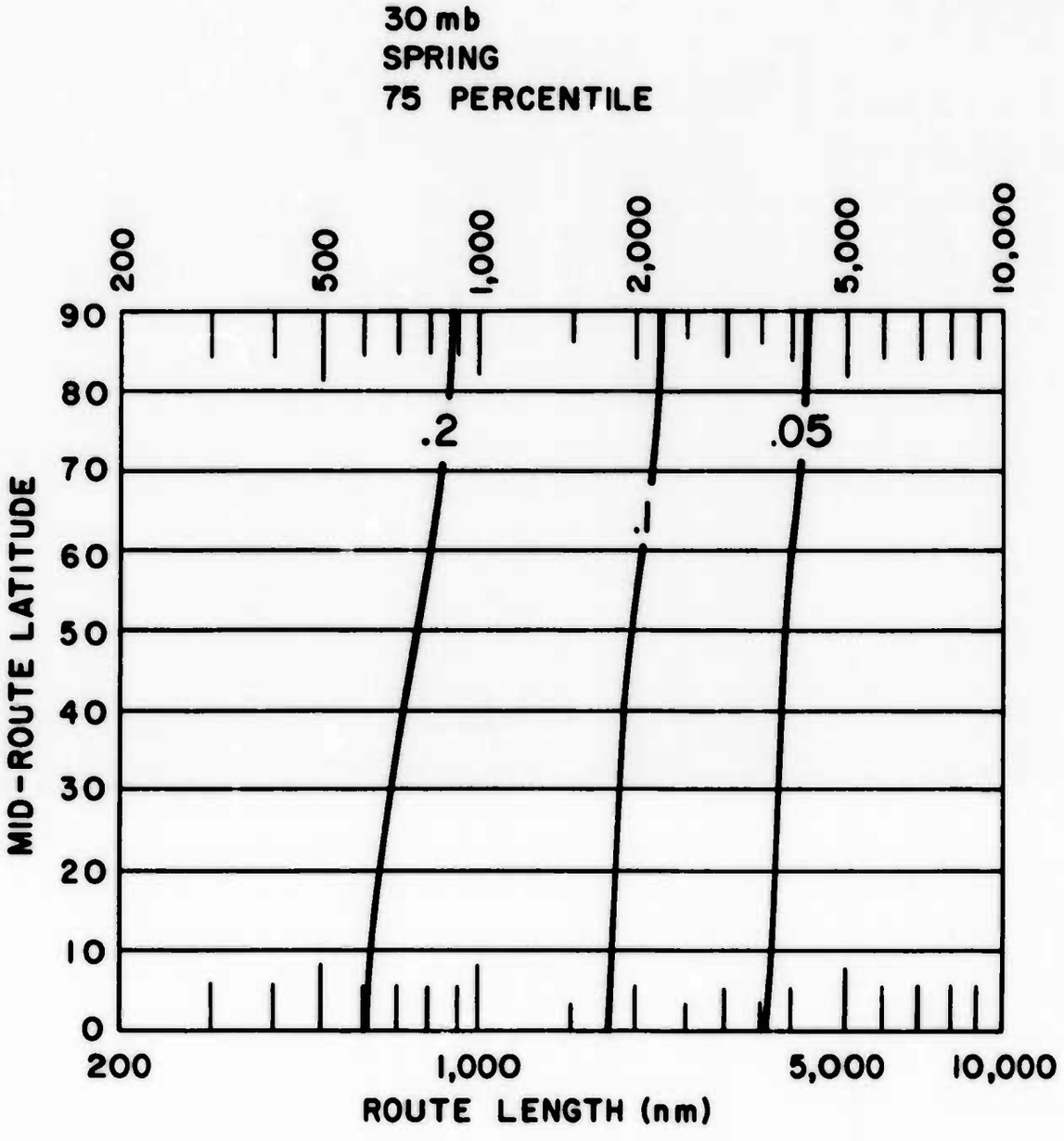


Plate 68. Temperature at 30 mb, in March, April, May, 75 Percentile



Graph 68. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

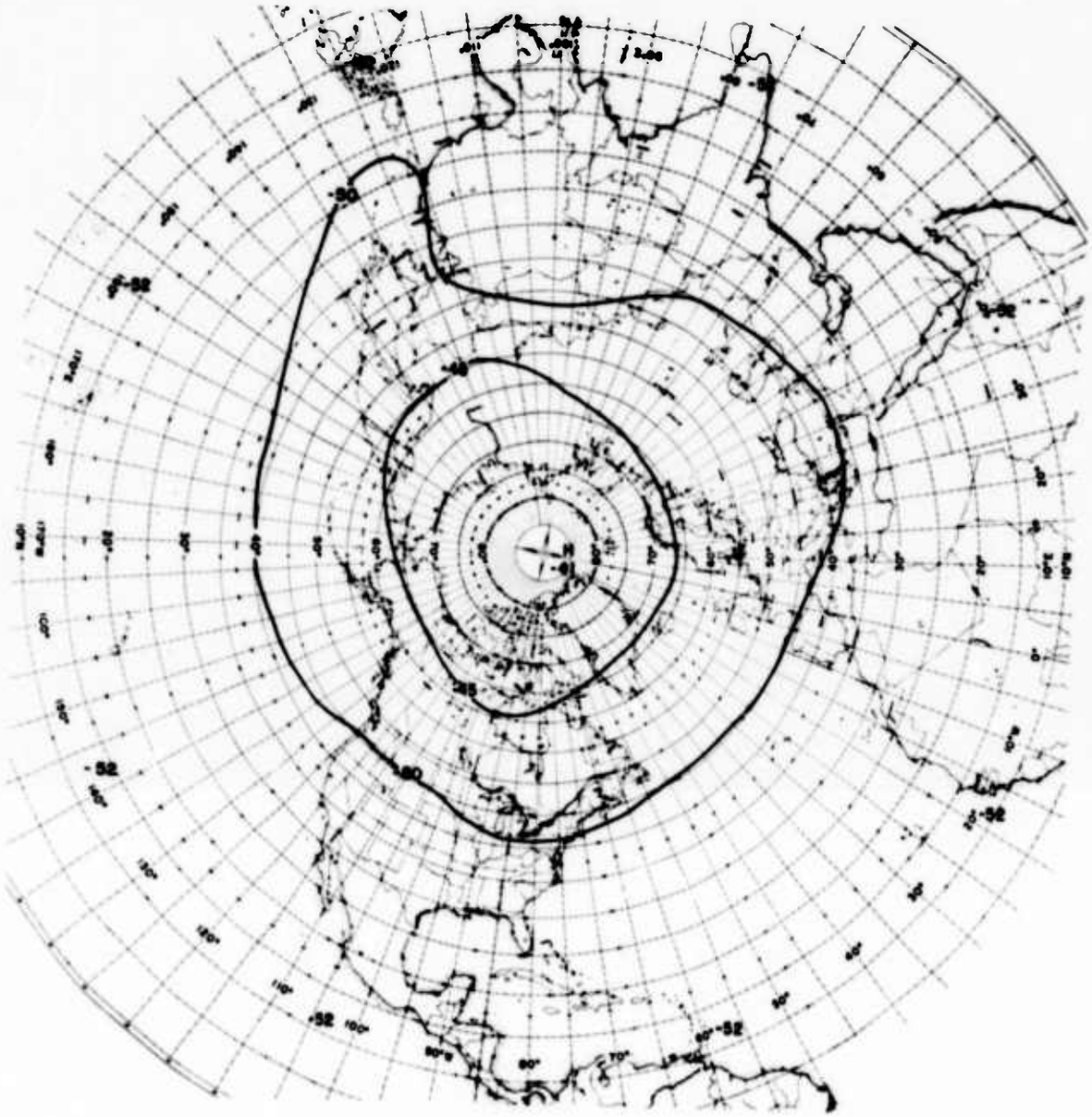
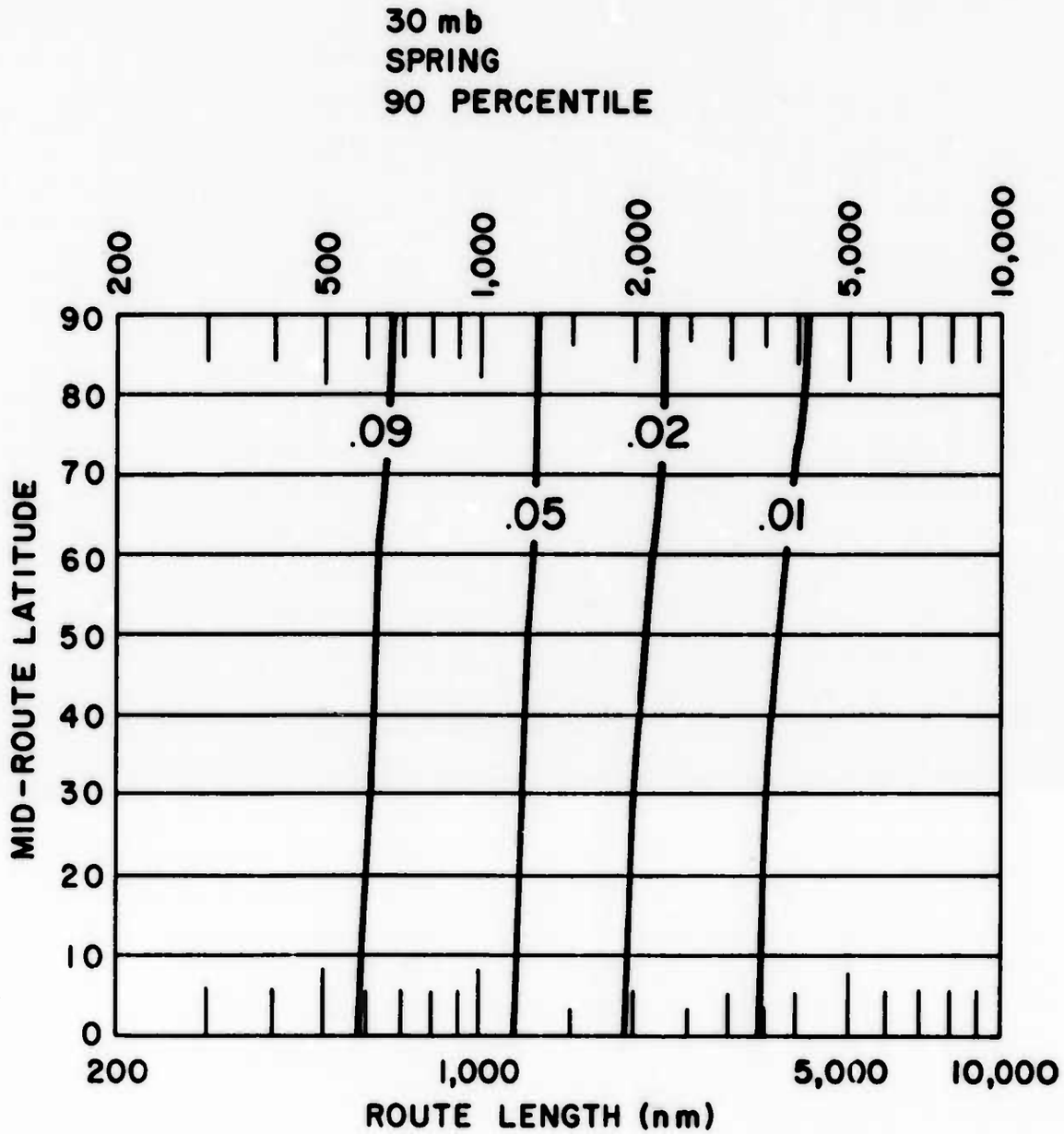


Plate 69. Temperature at 30 mb, in March, April, May, 90 Percentile



Graph 69. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

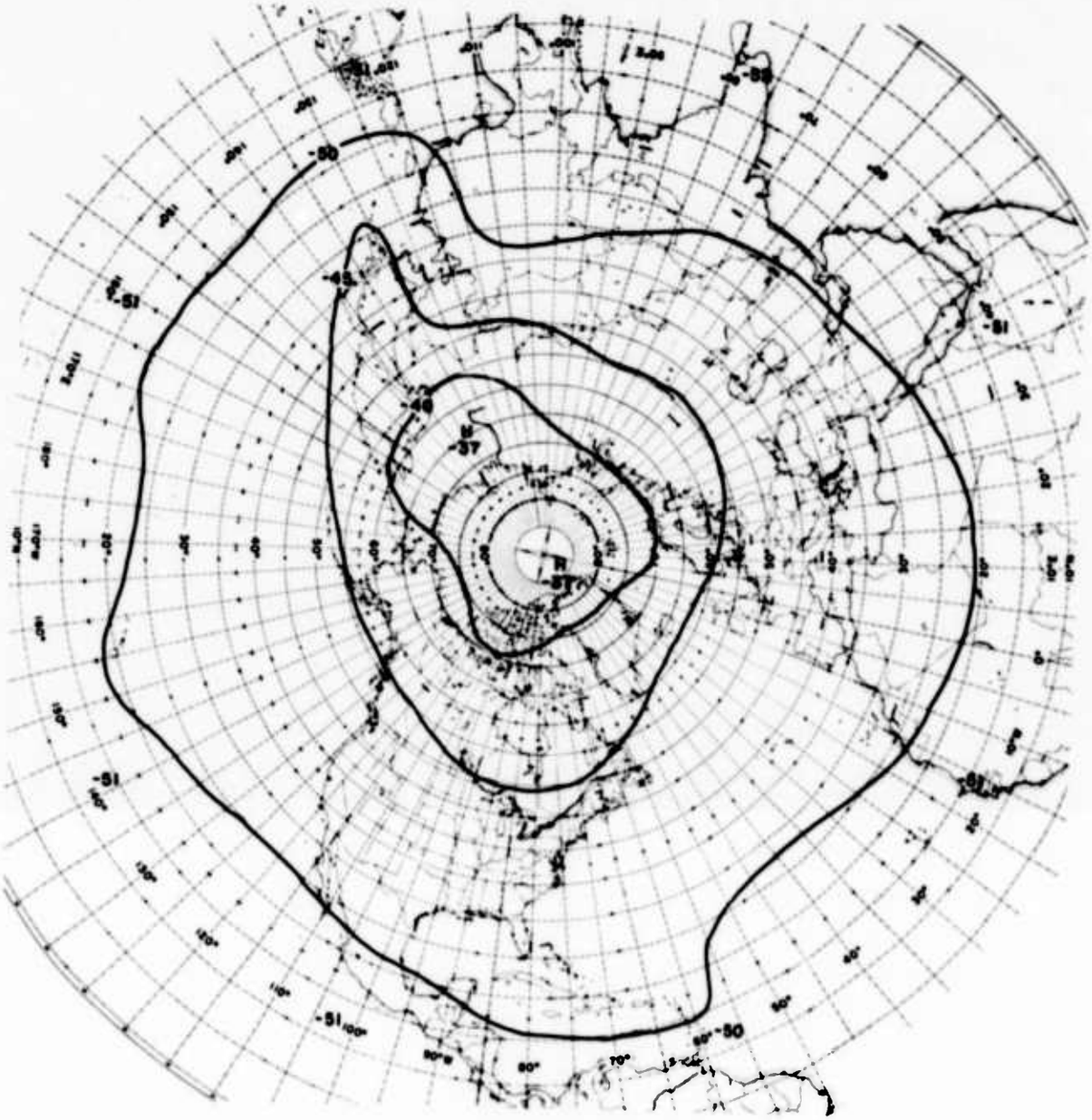
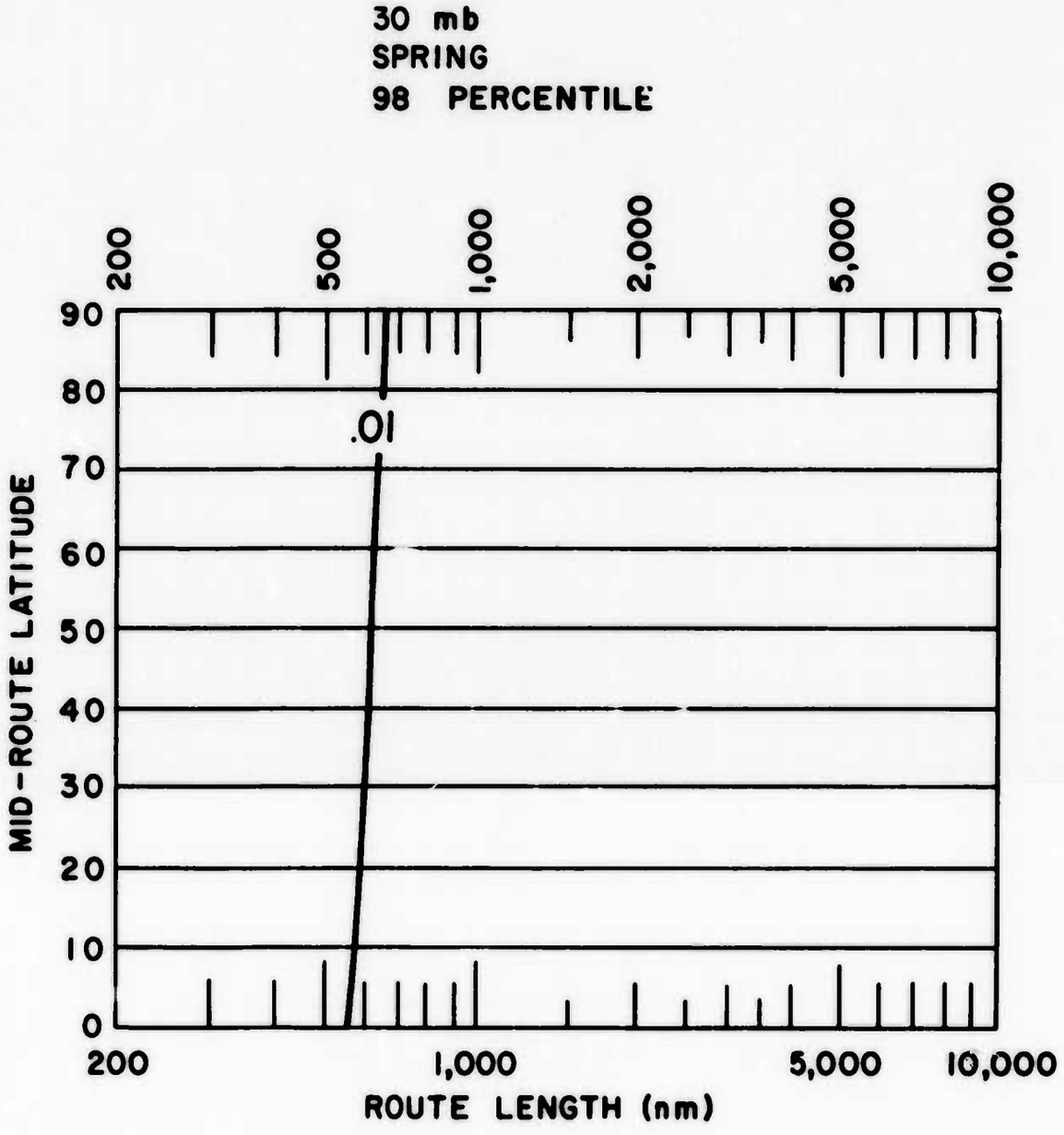


Plate 70. Temperature at 30 mb, in March, April, May, 98 Percentile



Graph 70. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

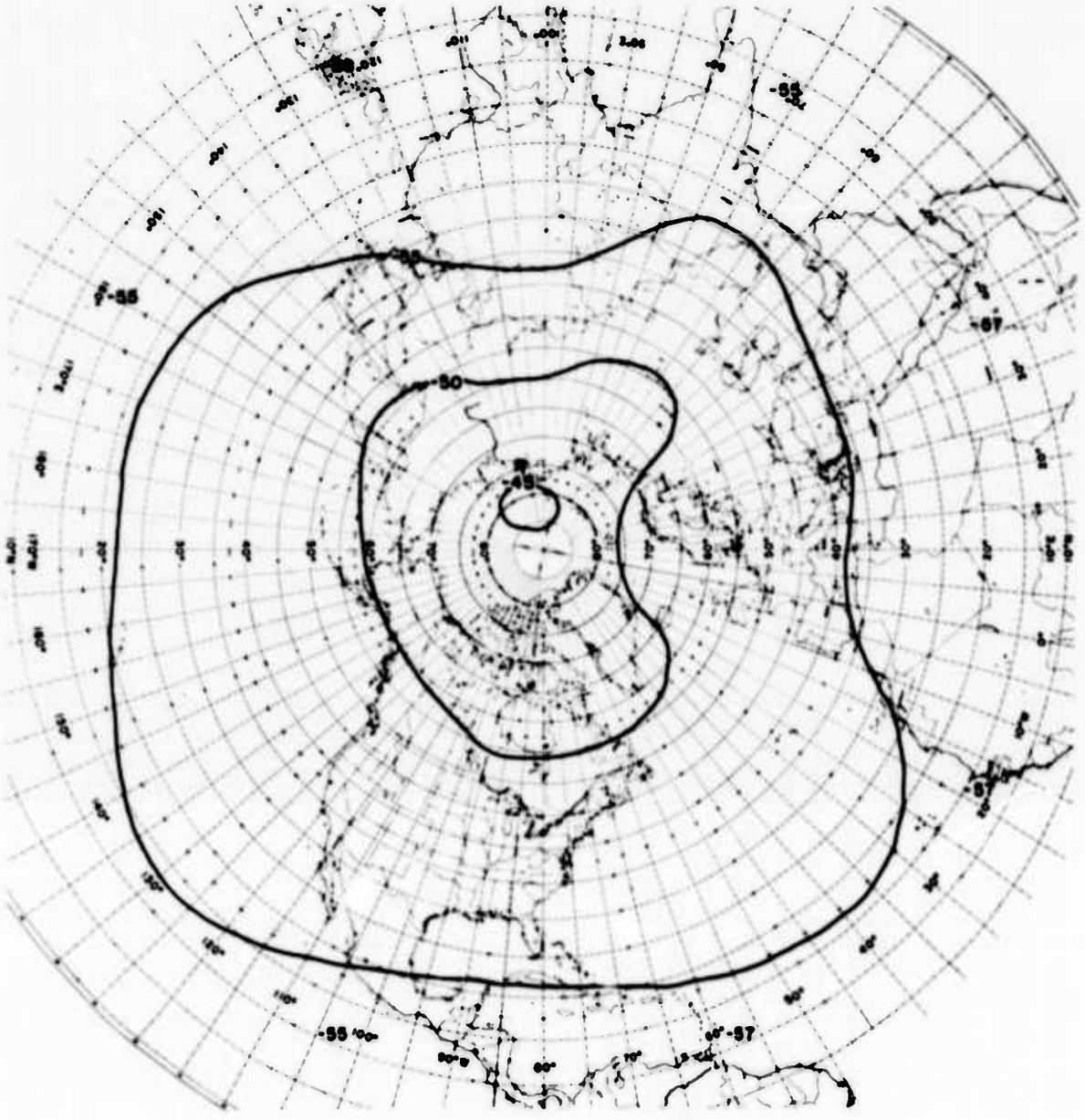
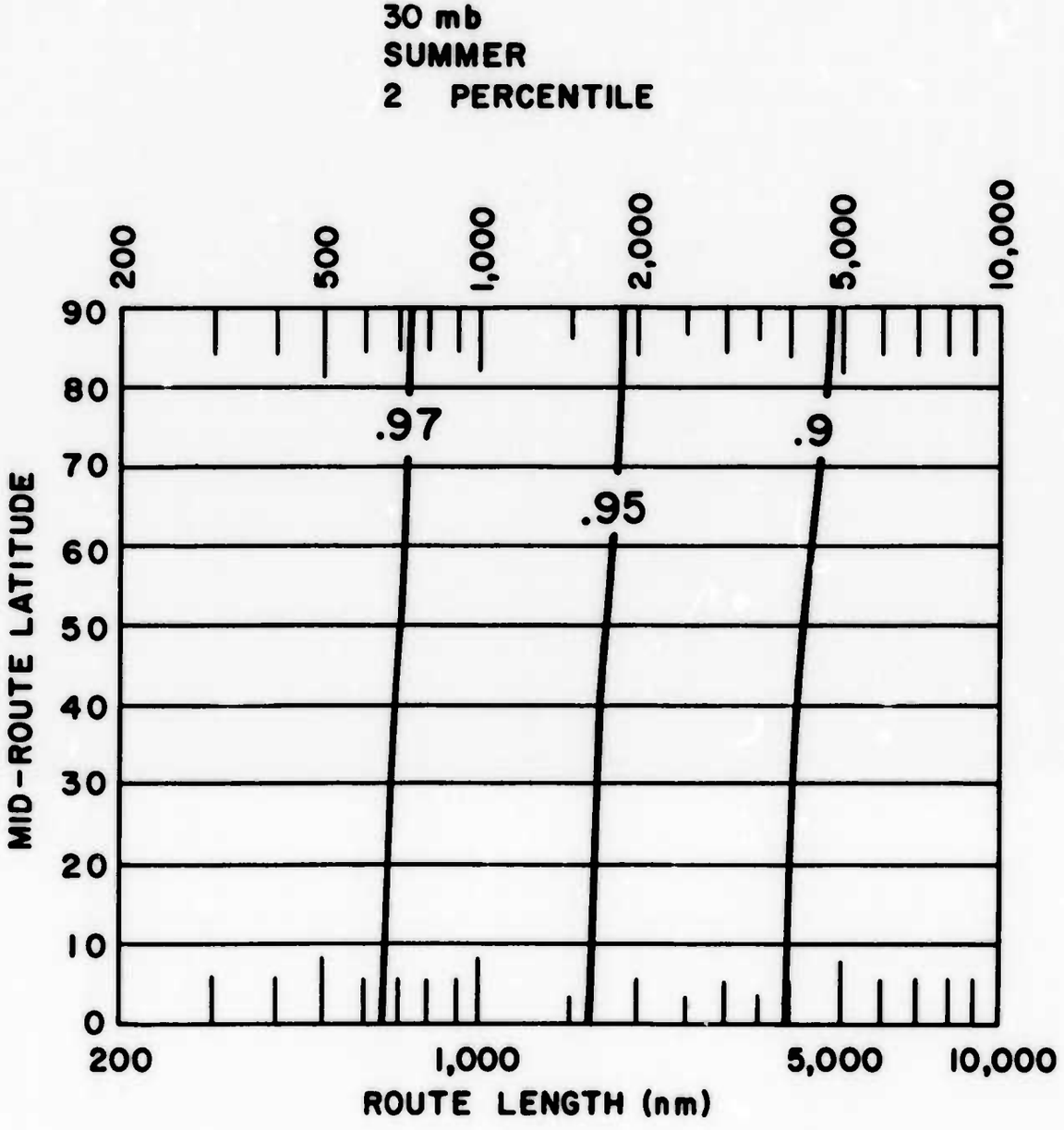


Plate 71. Temperature at 30 mb, in June, July, August, 2 Percentile



Graph 71. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

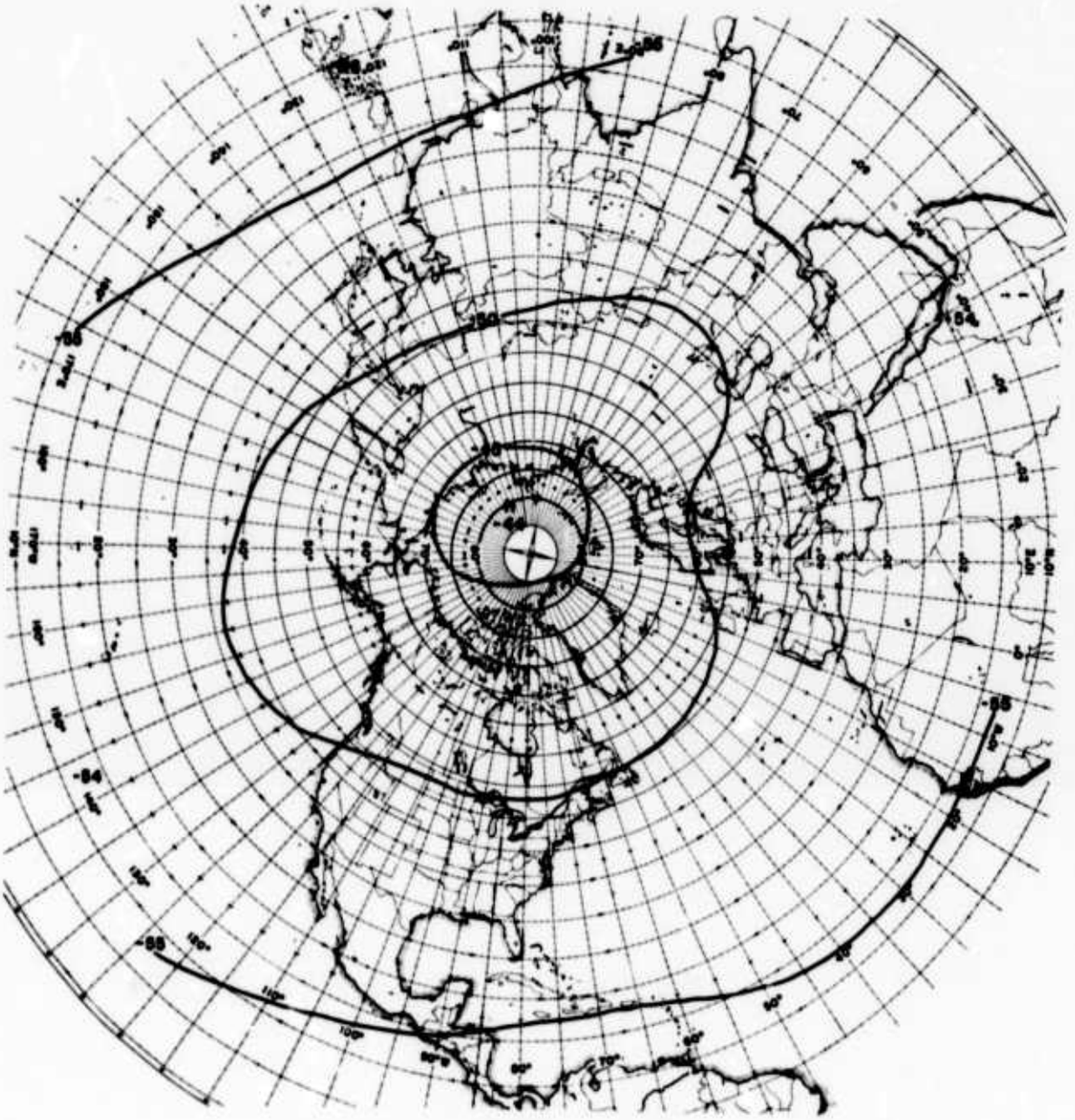
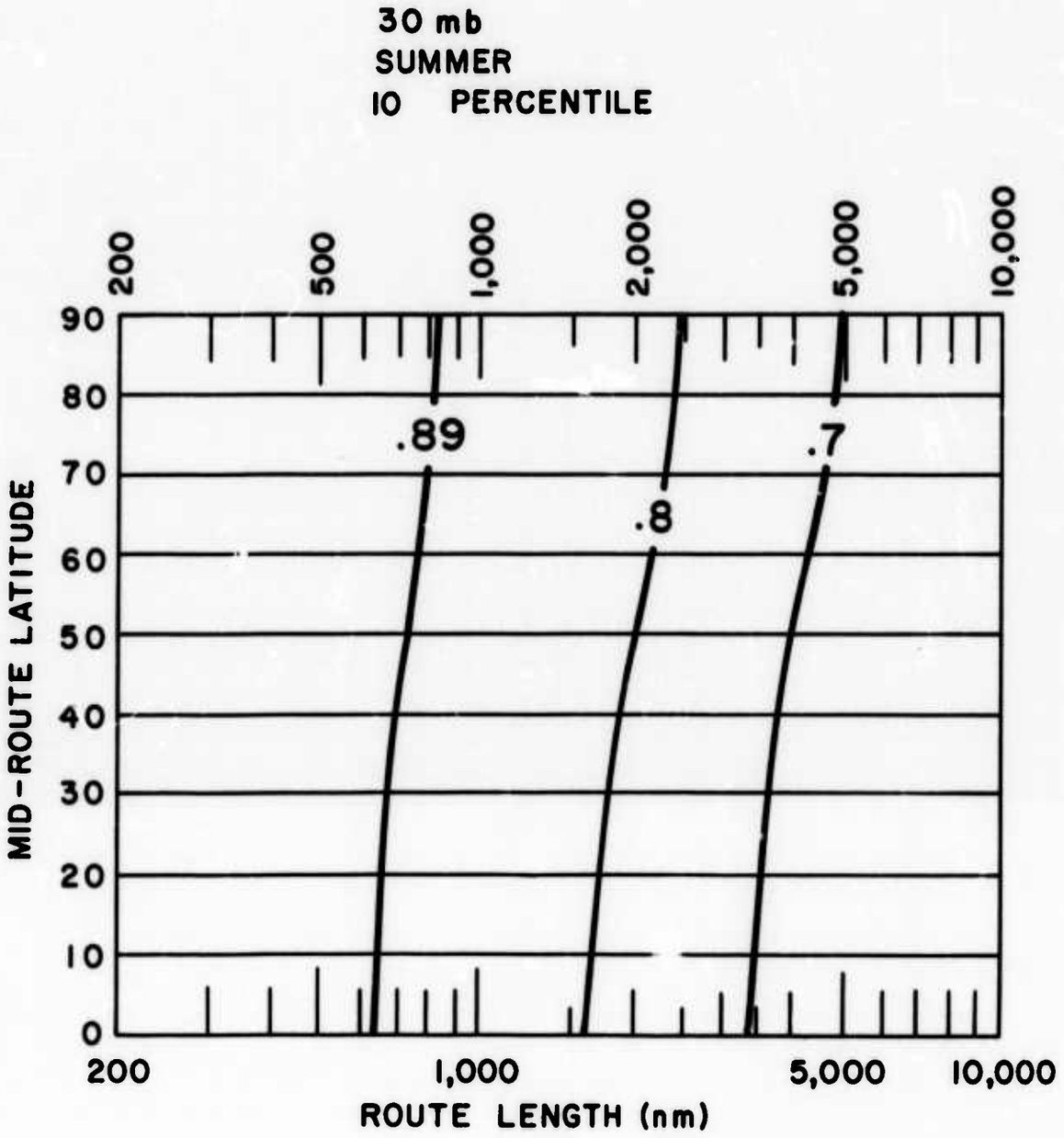


Plate 72. Temperature at 30 mb, in June, July, August, 10 Percentile



Graph 72. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

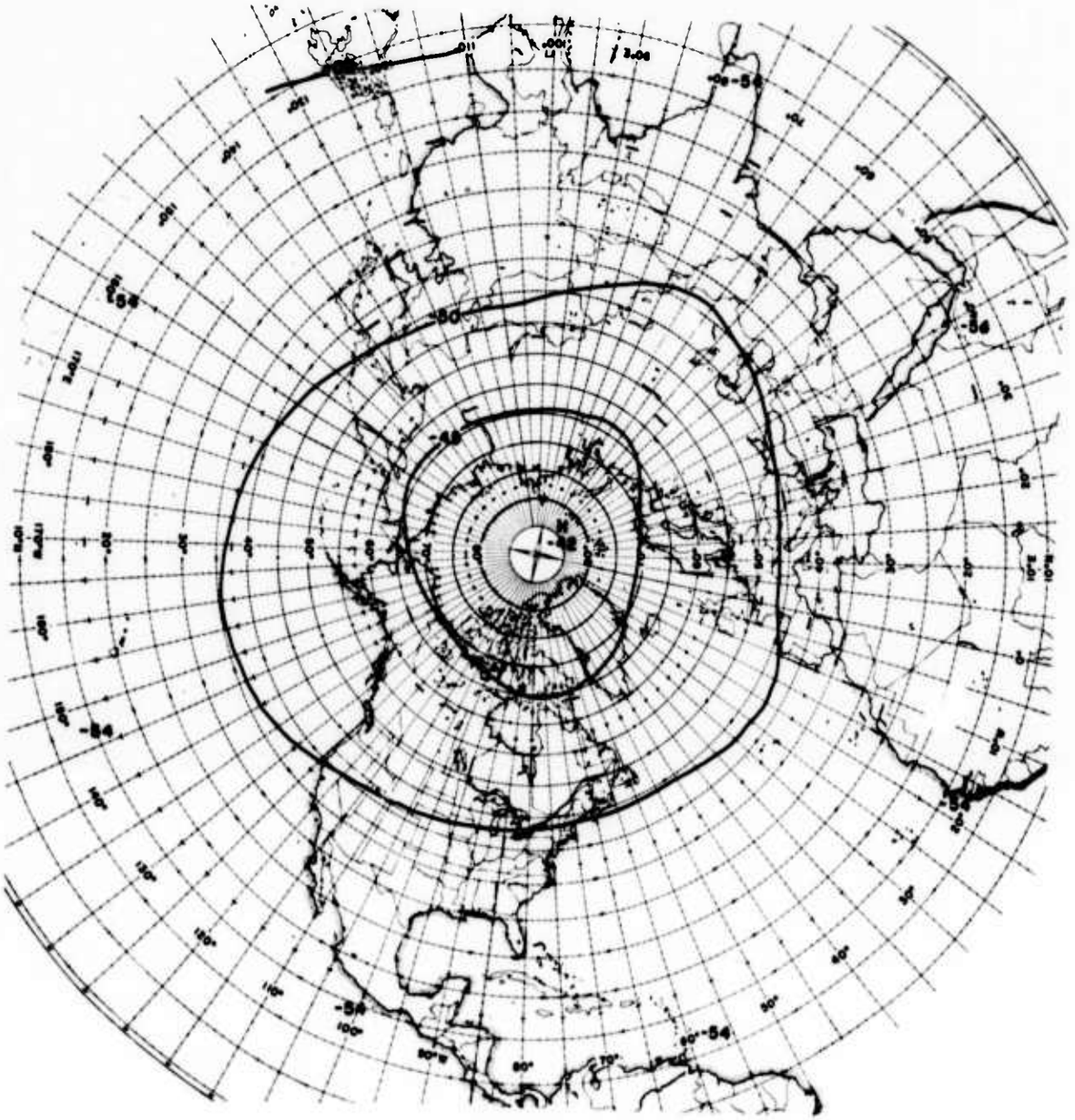
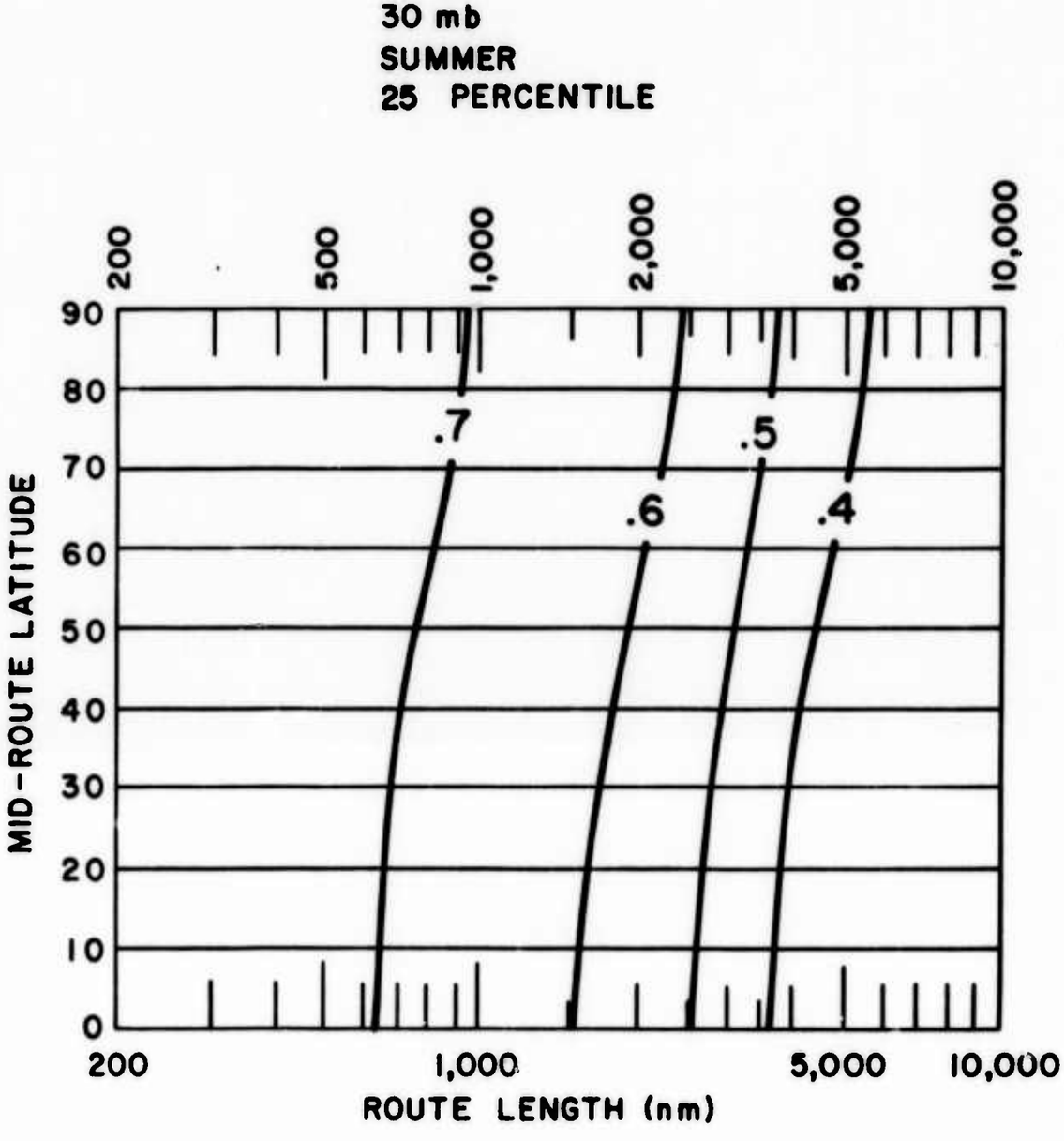
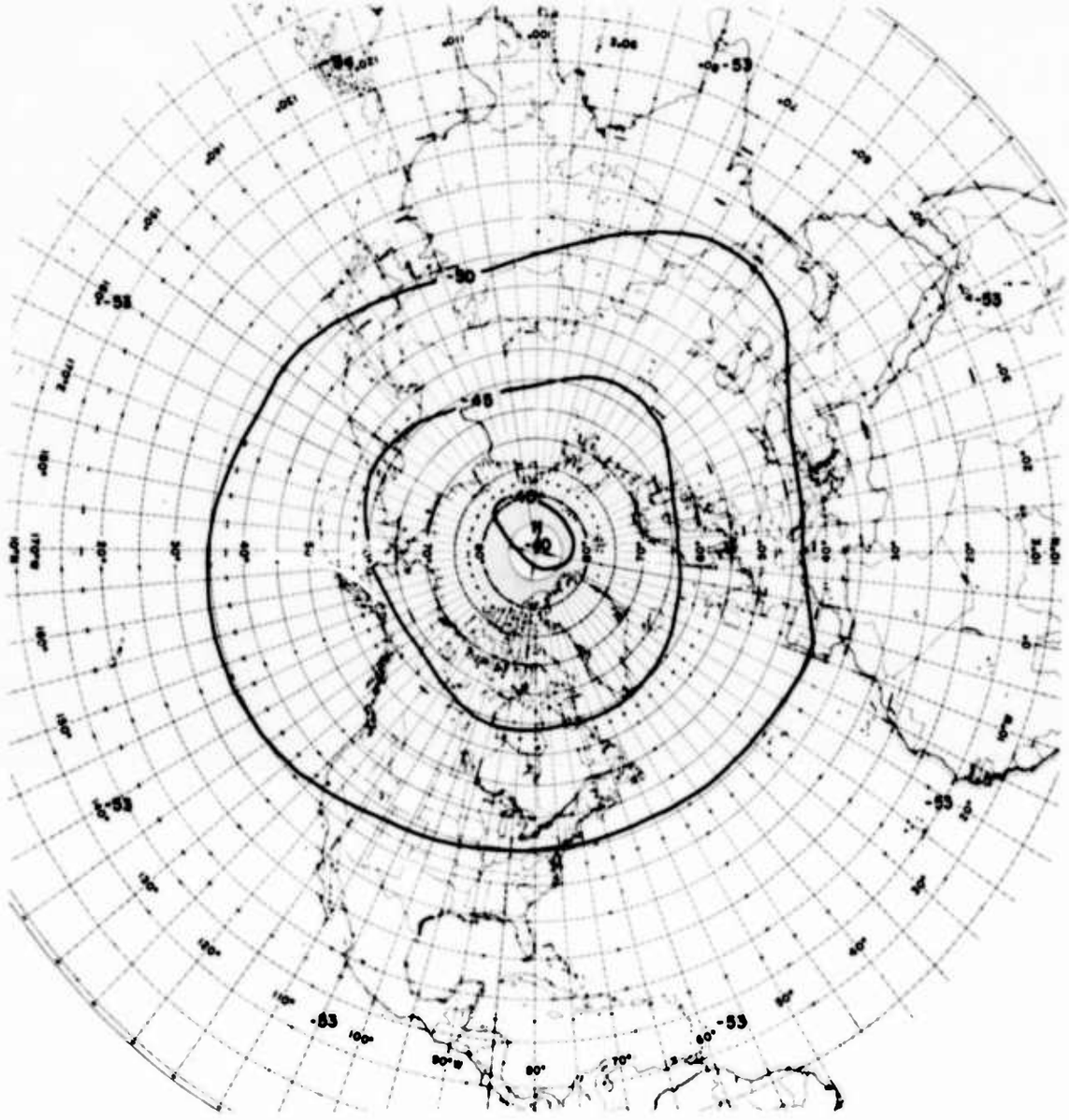


Plate 73. Temperature at 30 mb, in June, July, August, 25 Percentile



Graph 73. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page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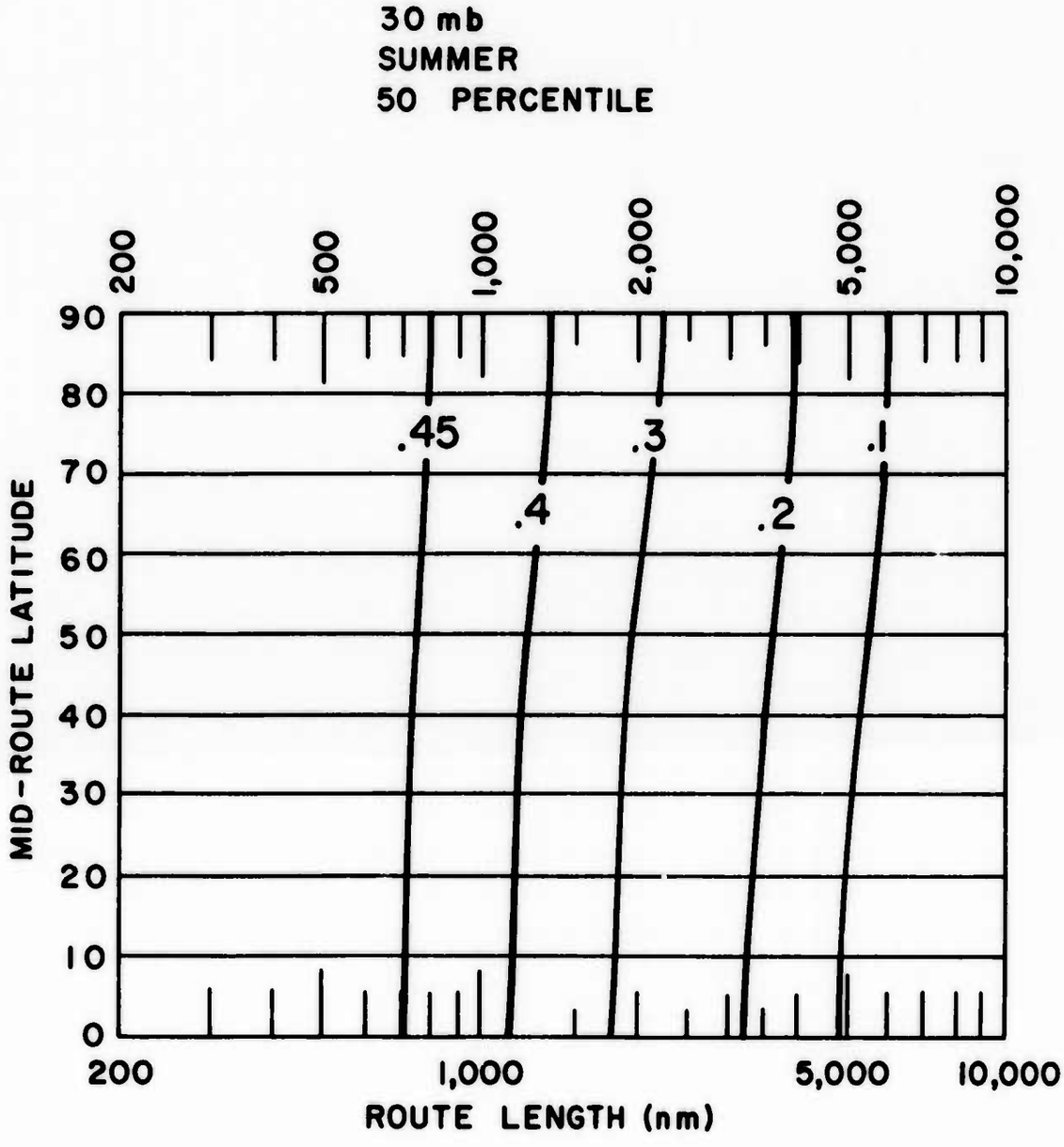
-42
-53
-53
-53



Graph 74. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

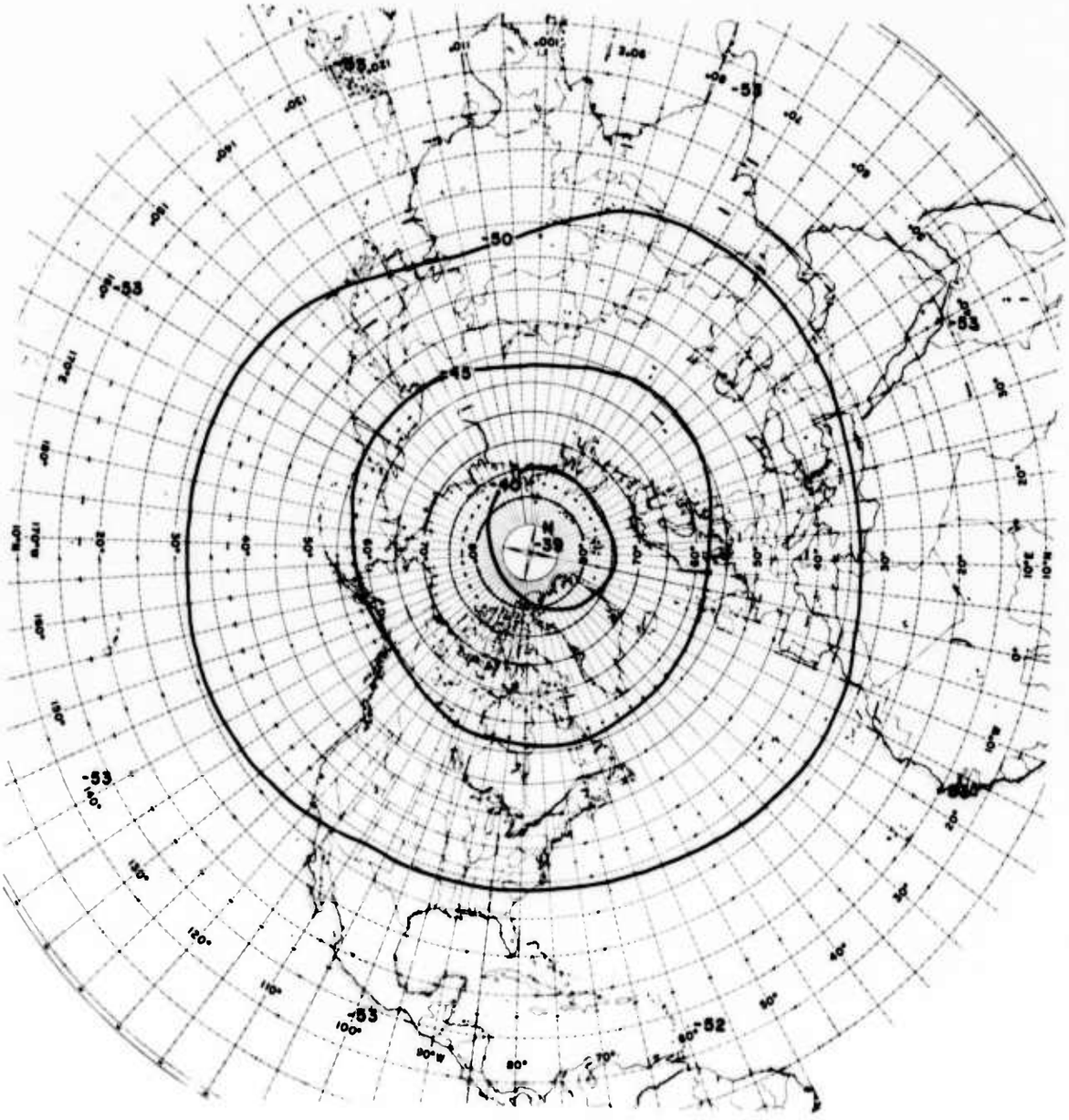
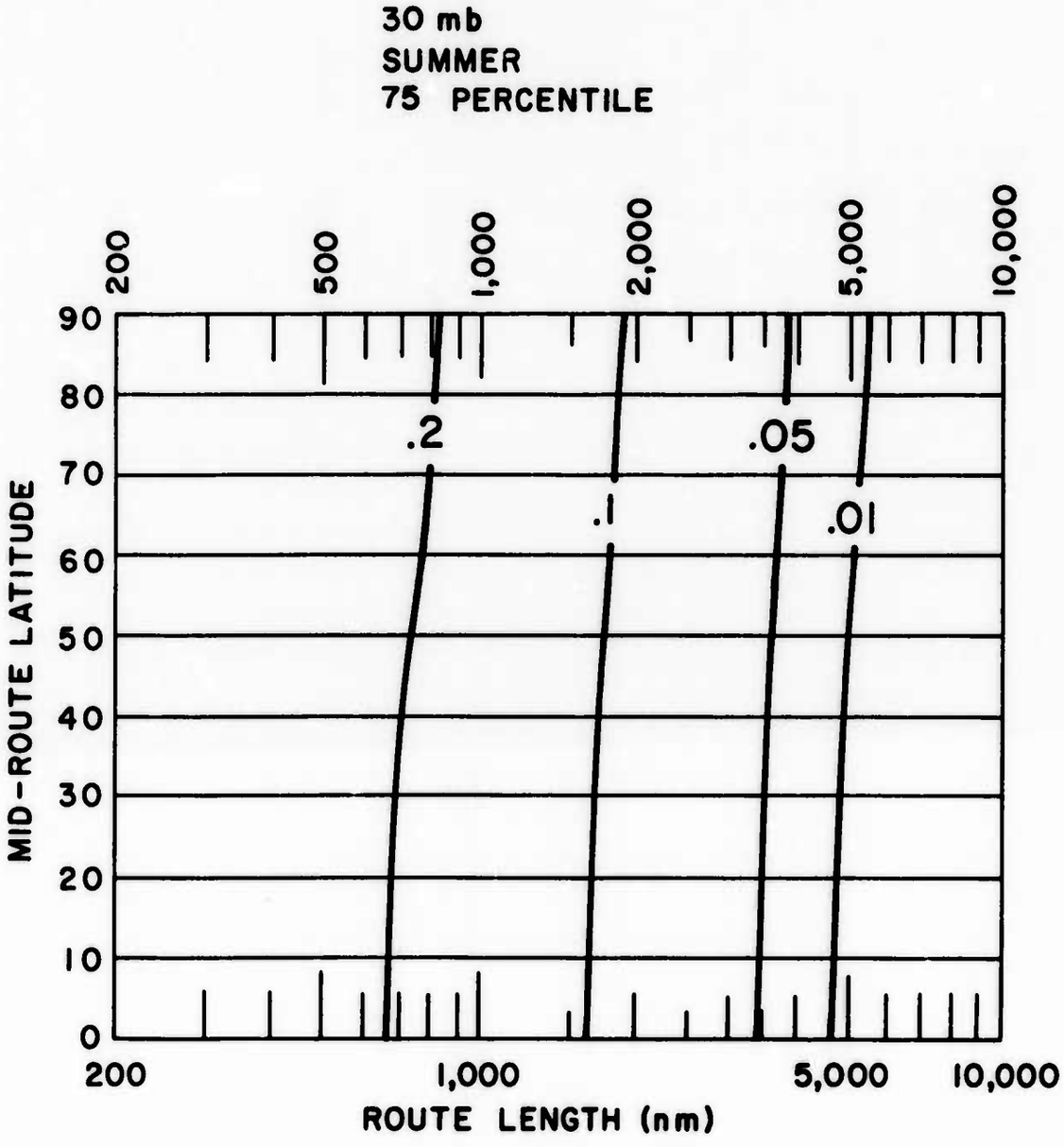


Plate 75. Temperature at 30 mb, in June, July, August, 75 Percentile



Graph 75. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

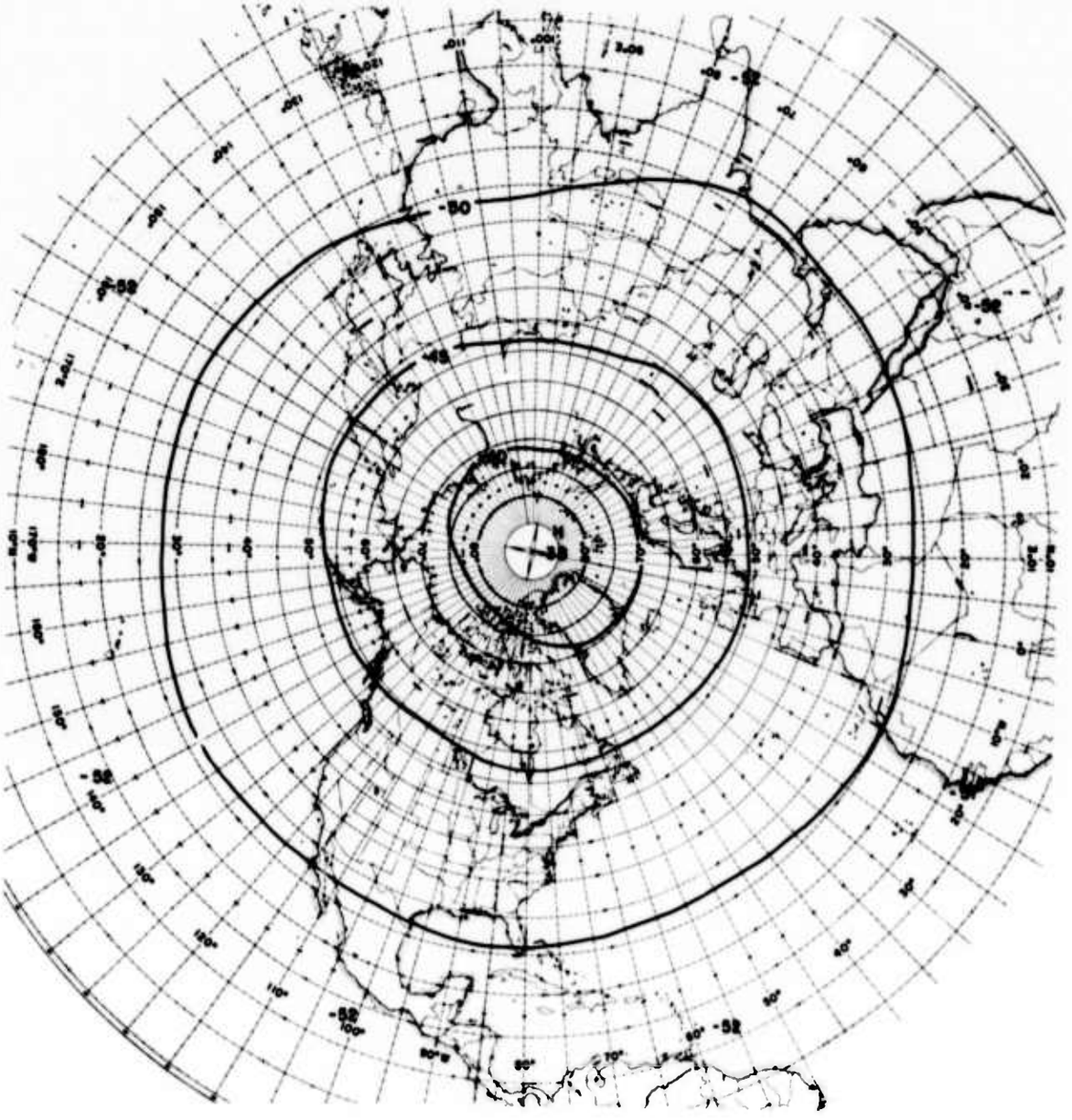
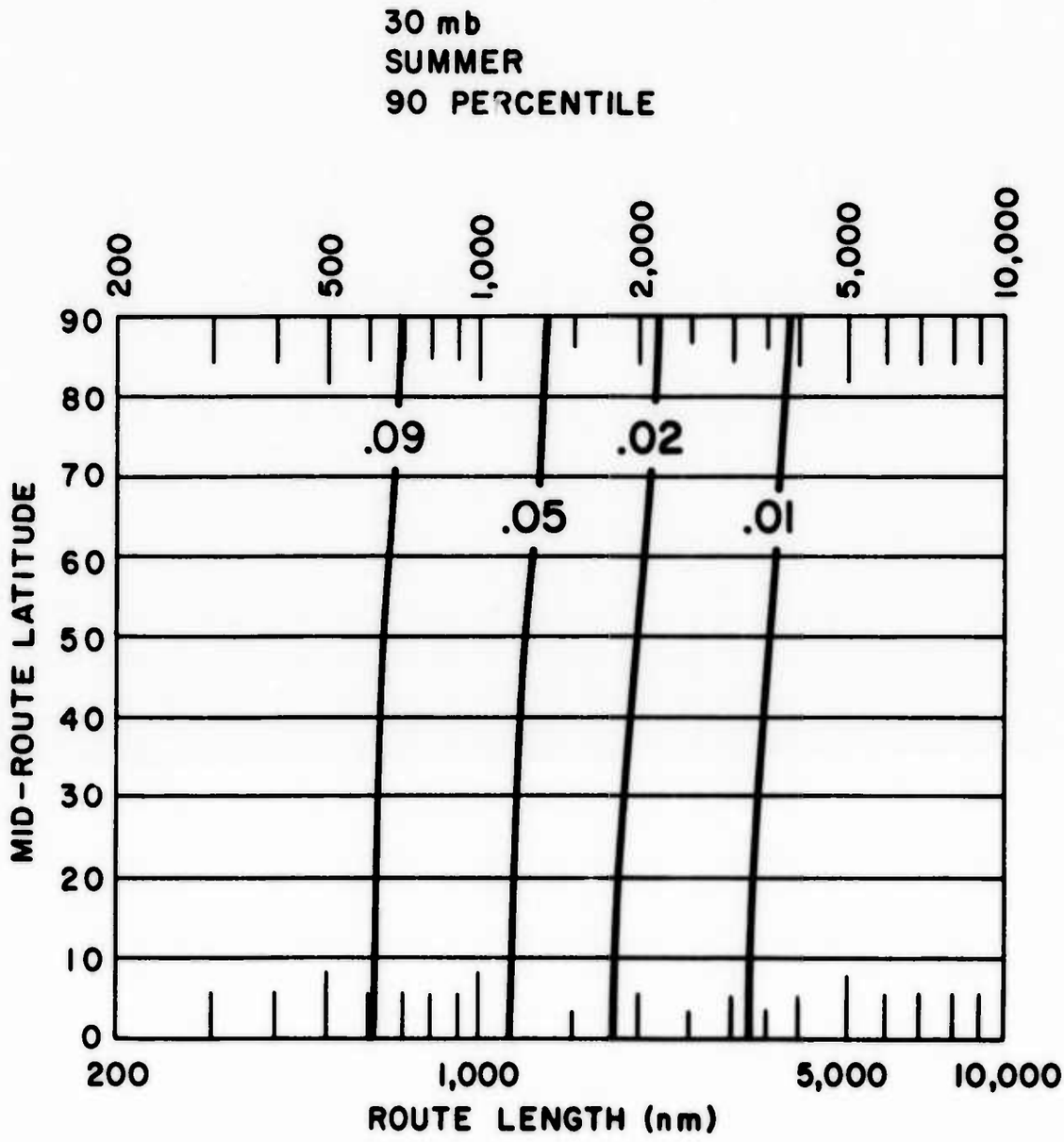


Plate 76. Temperature at 30 mb, in June, July, August, 90 Percentile



Graph 76. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

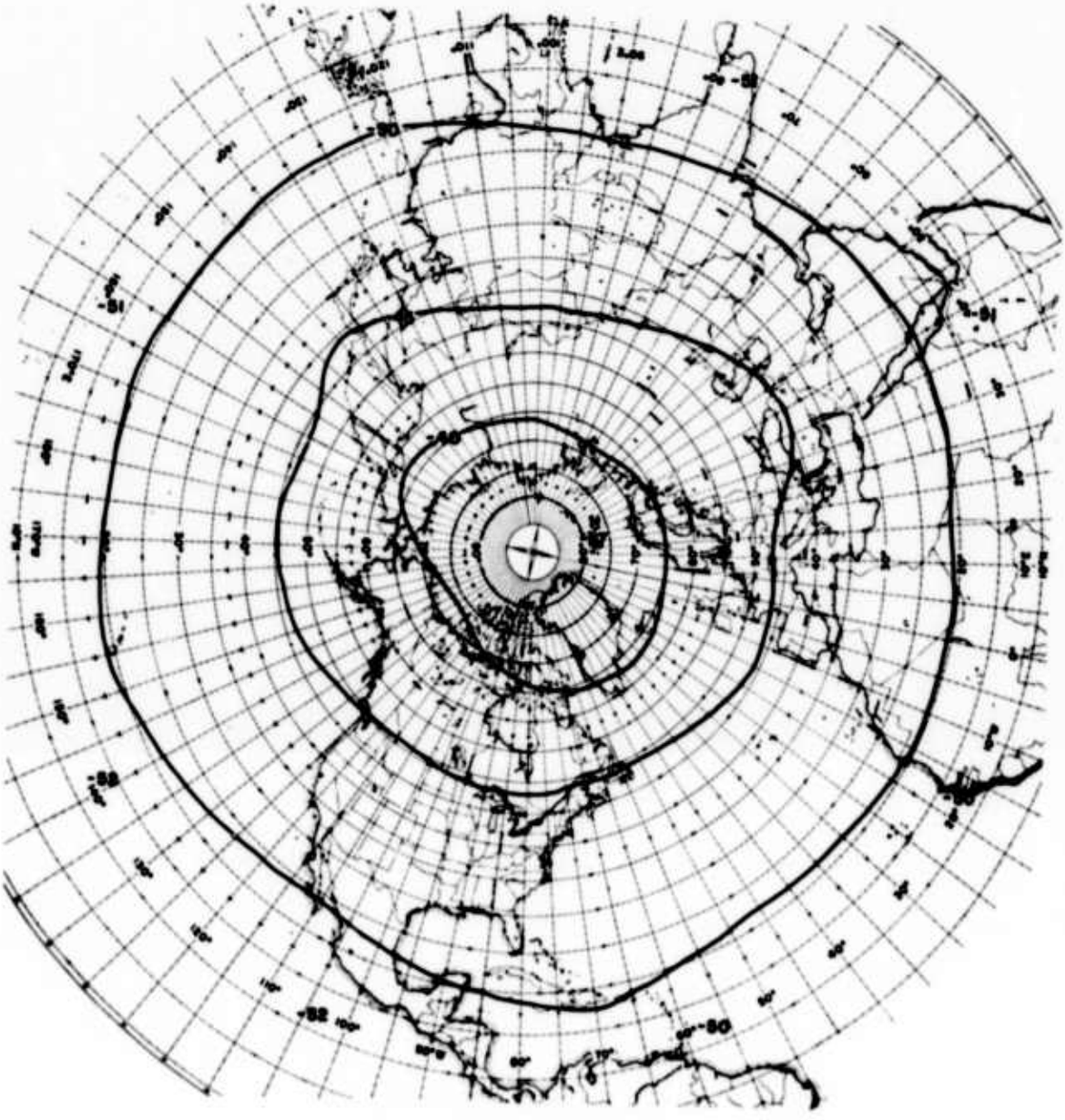
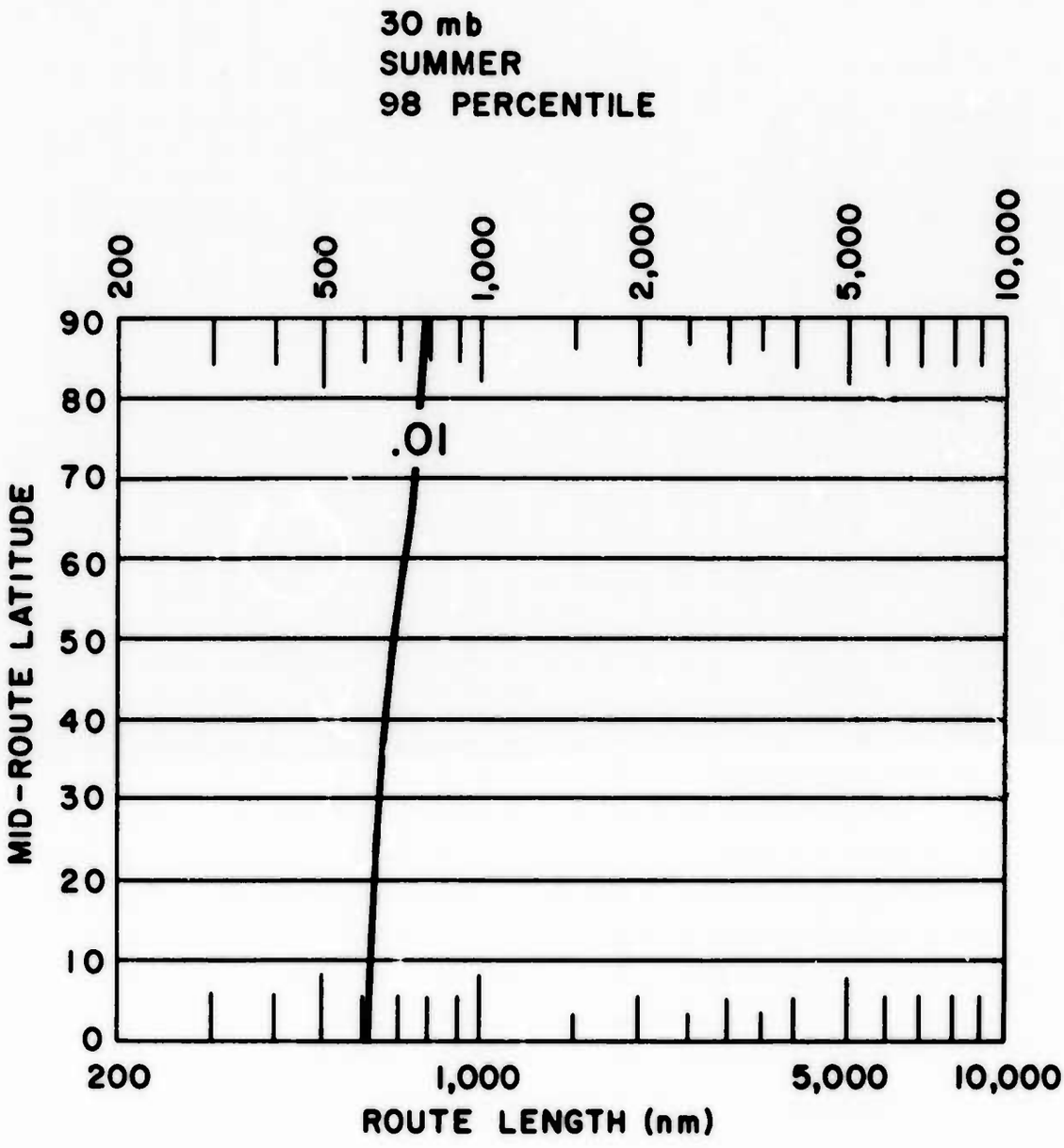


Plate 77. Temperature at 30 mb, in June, July, August, 98 Percentile



Graph 77. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

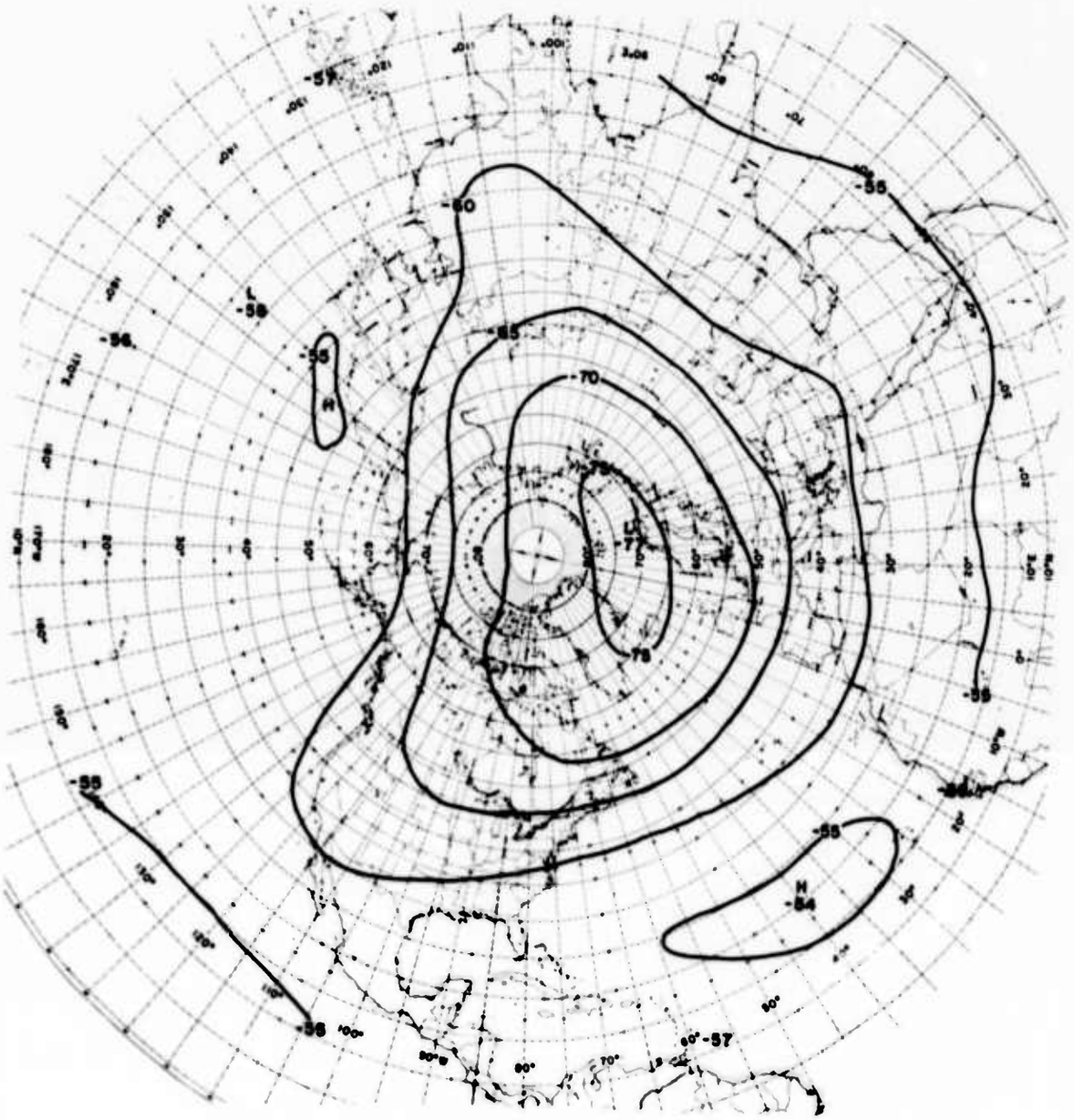
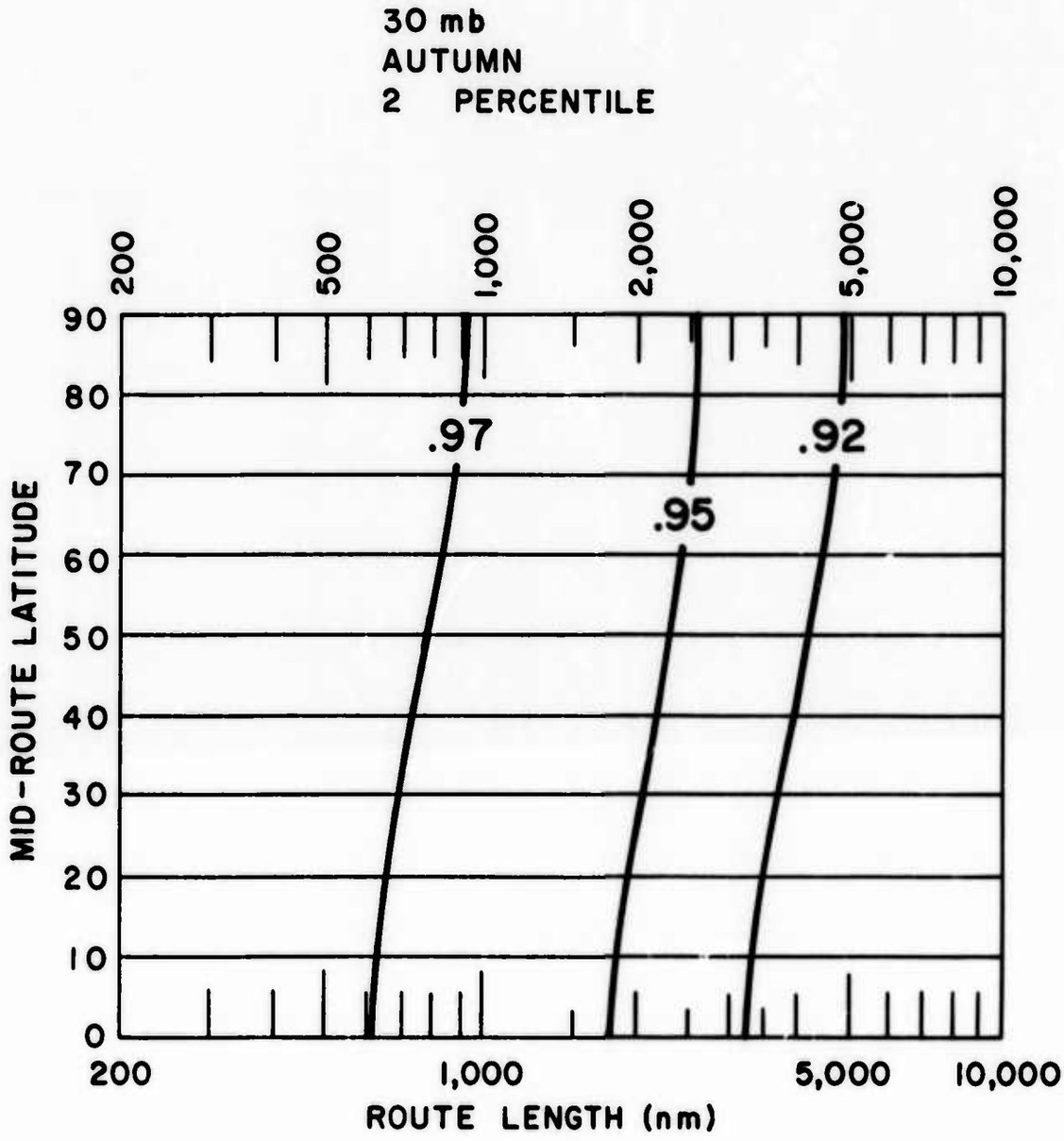


Plate 78. Temperature at 30 mb, in September, October, November, 2 Percentile



Graph 78. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

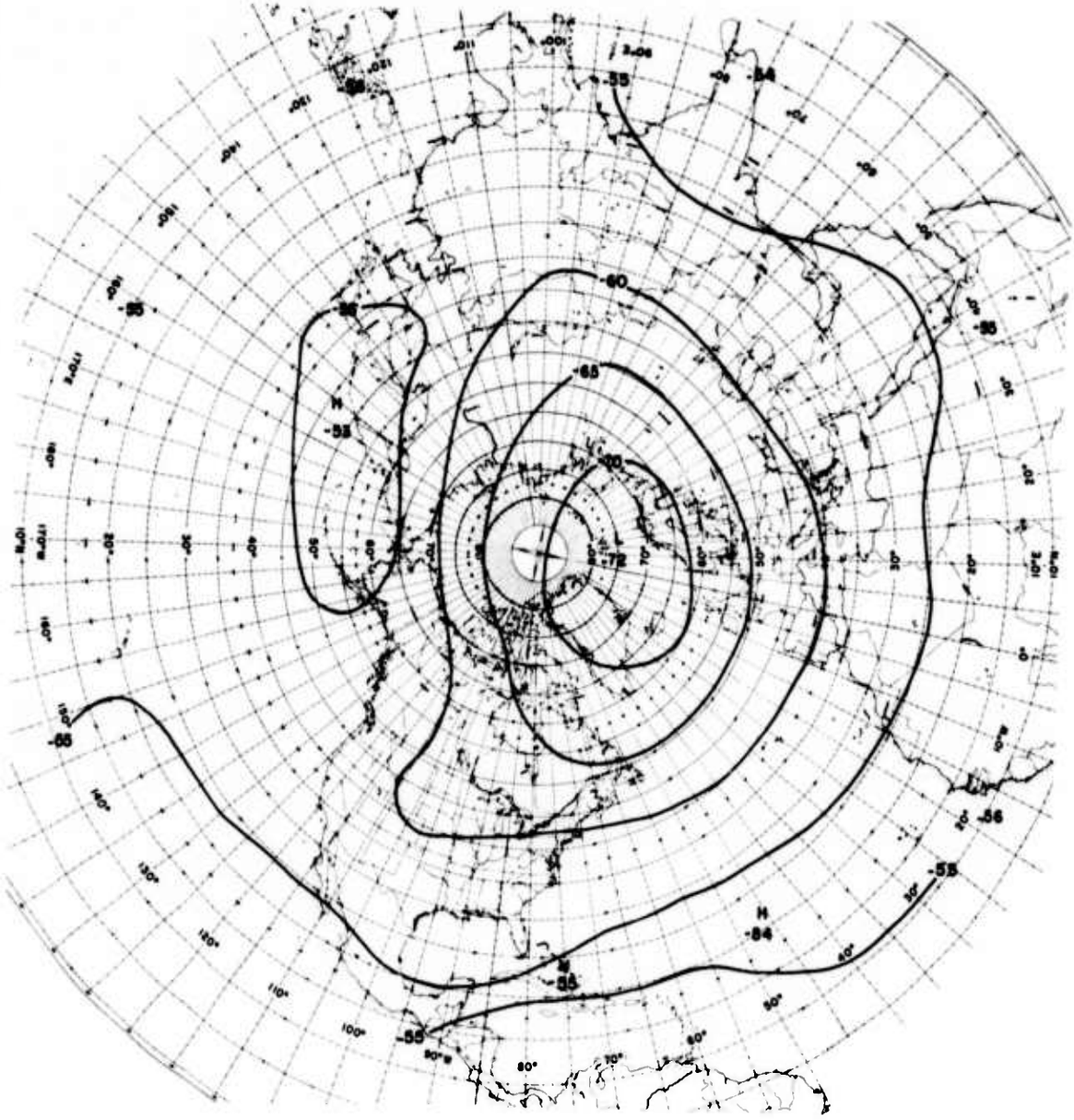
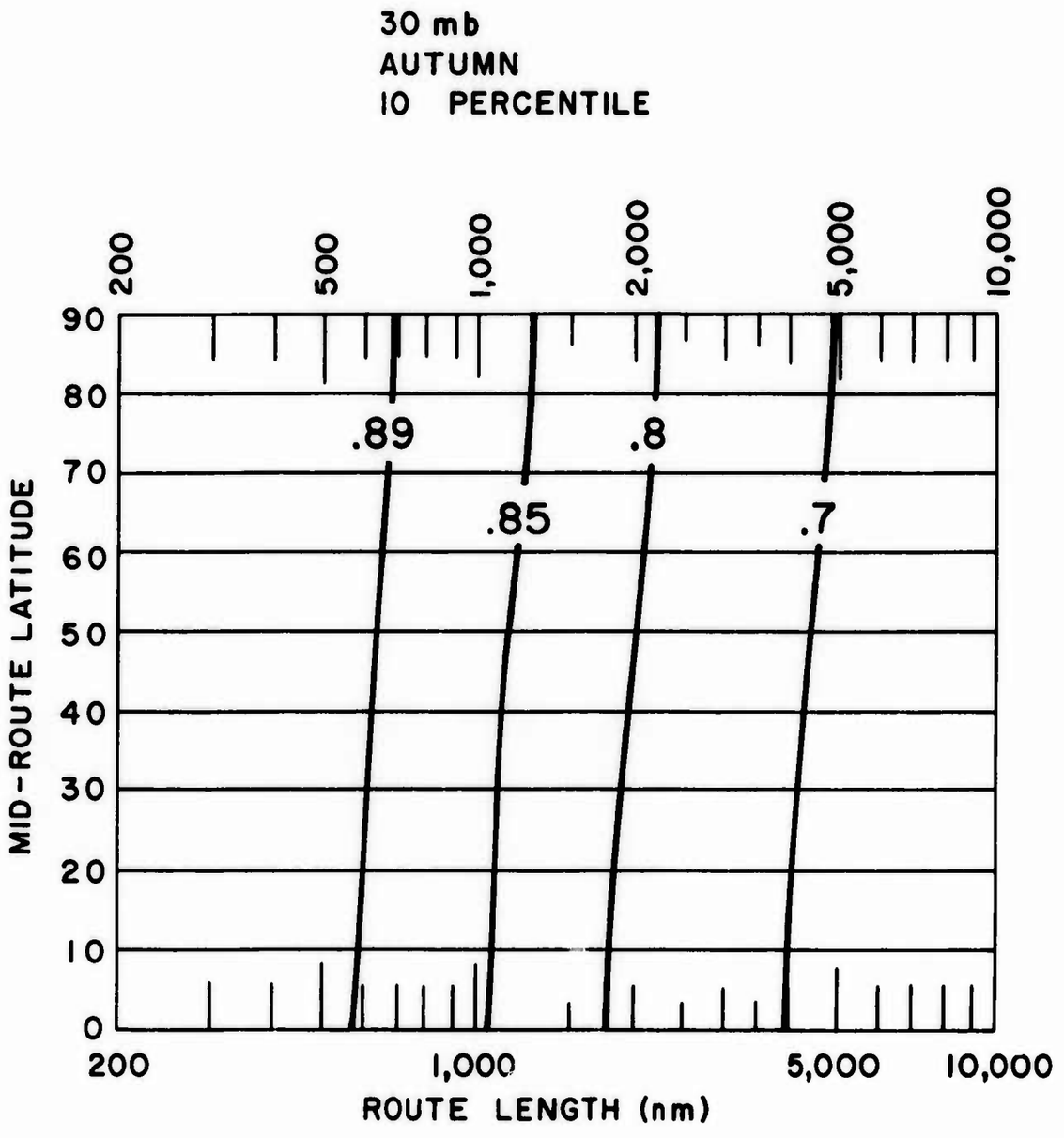


Plate 79. Temperature at 30 mb, in September, October, November, 10 Percentile



Graph 79. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

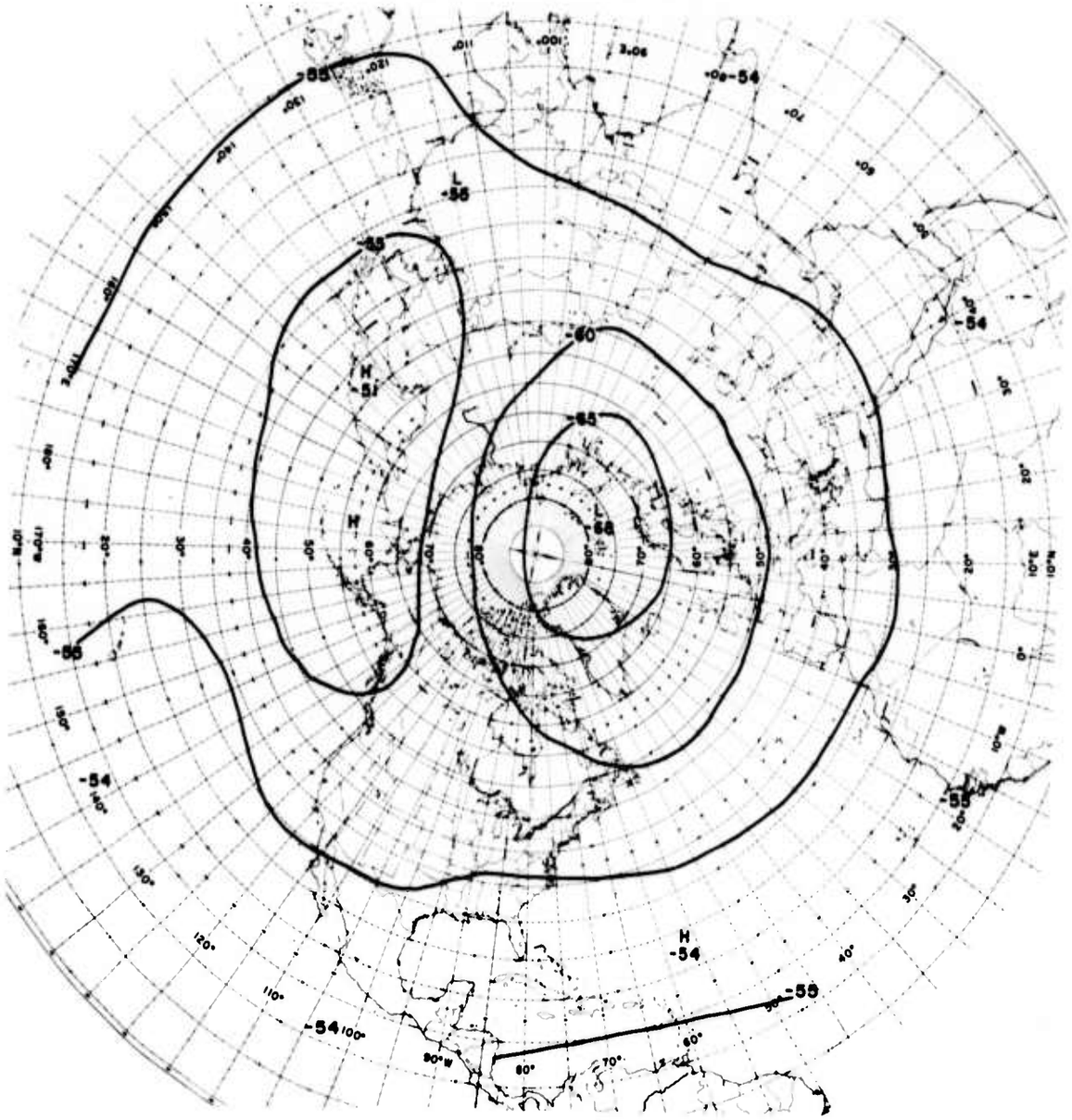
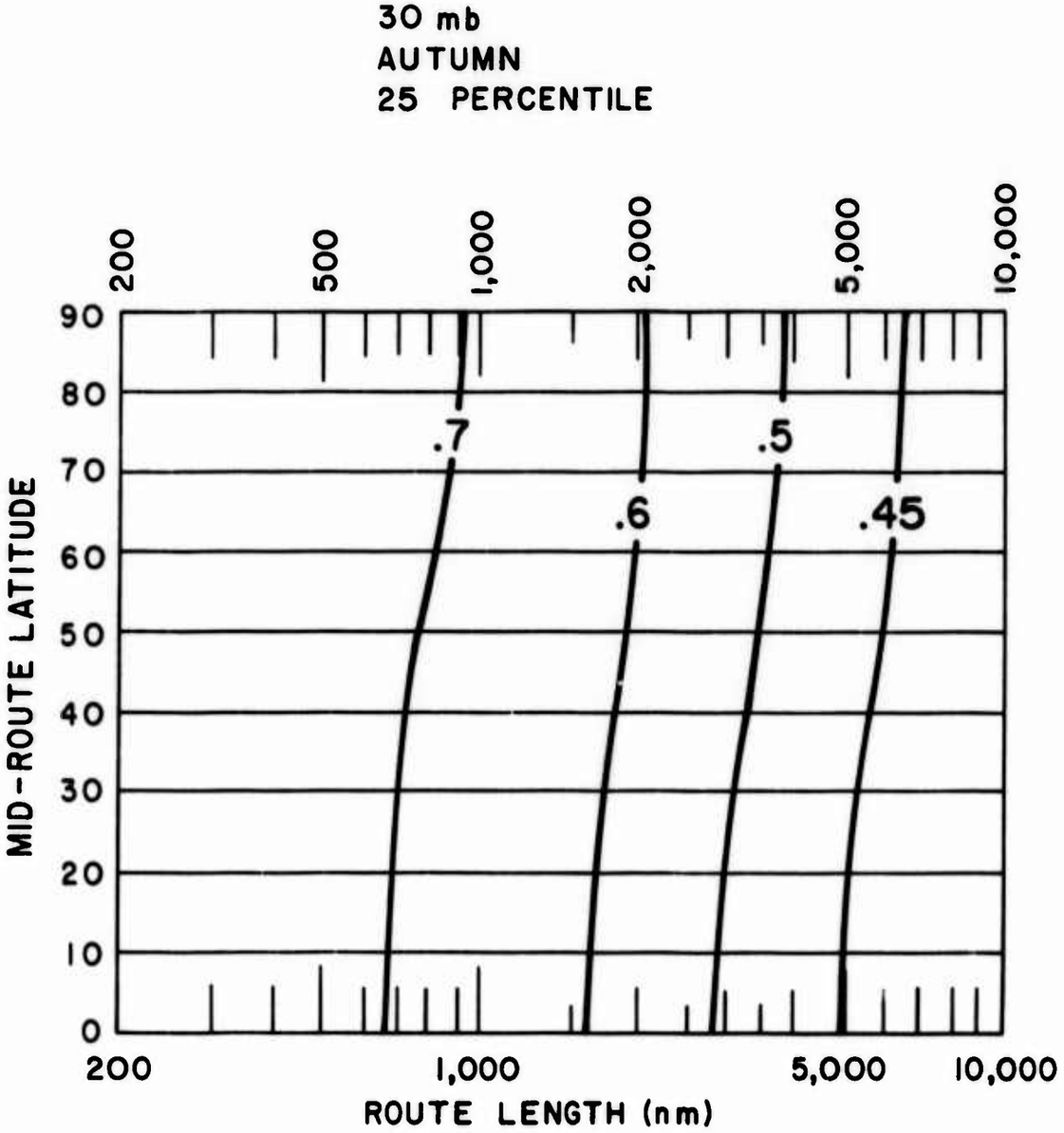


Plate 80. Temperature at 30 mb, in September, October, November, 25 Percentile



Graph 80. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

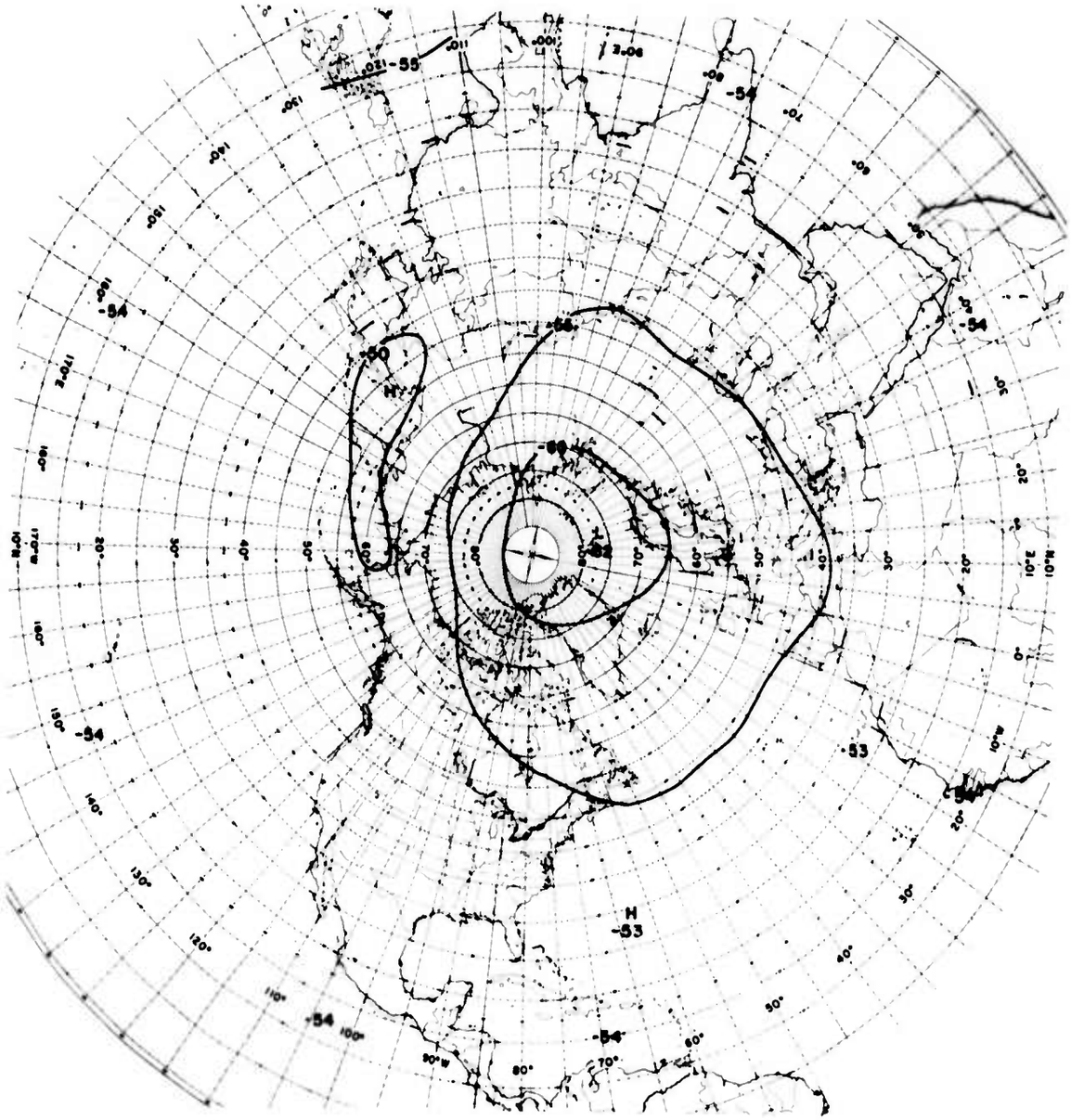
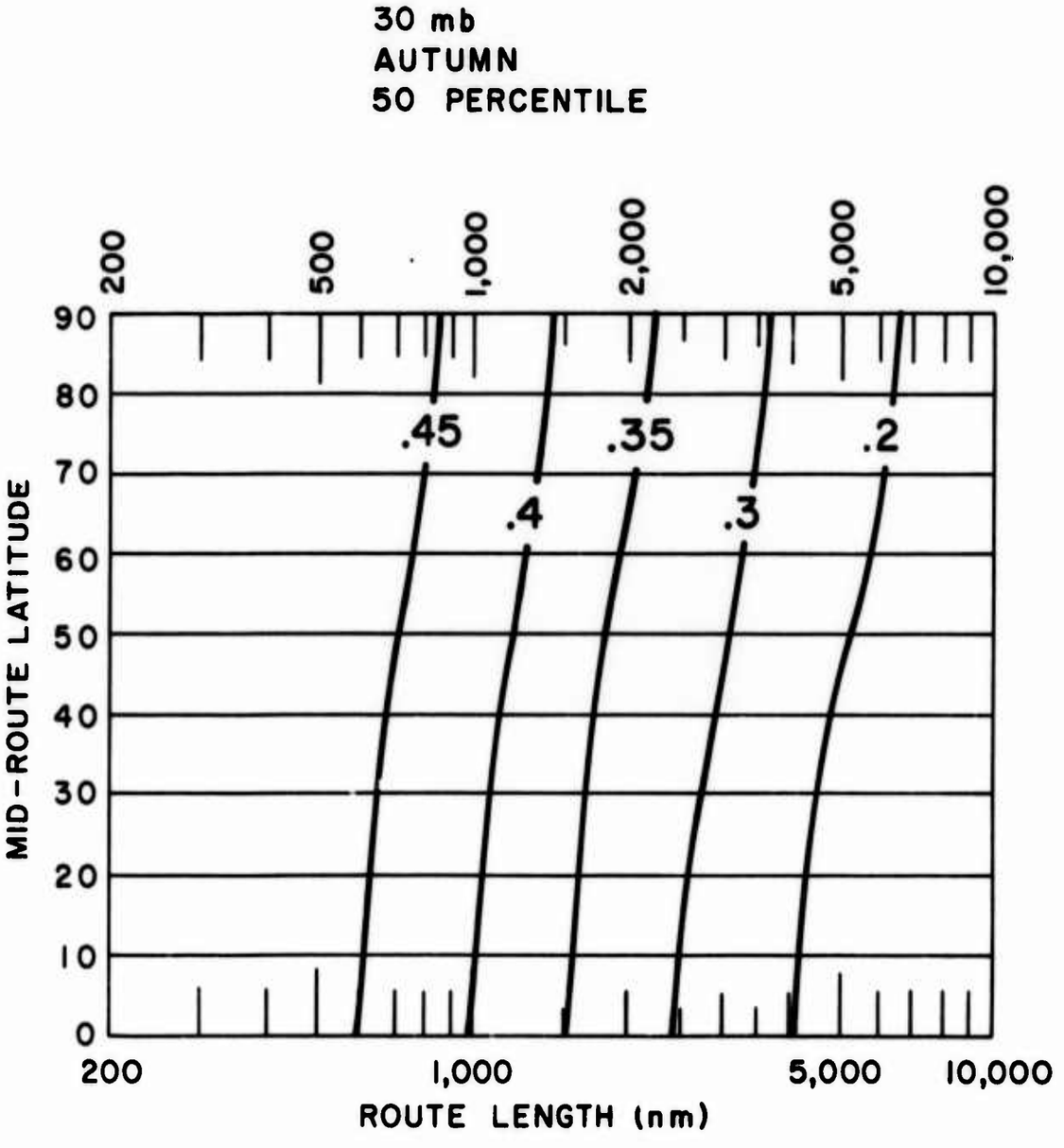


Plate 81. Temperature at 30 mb, in September, October, November, 50 Percentile



Graph 81. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

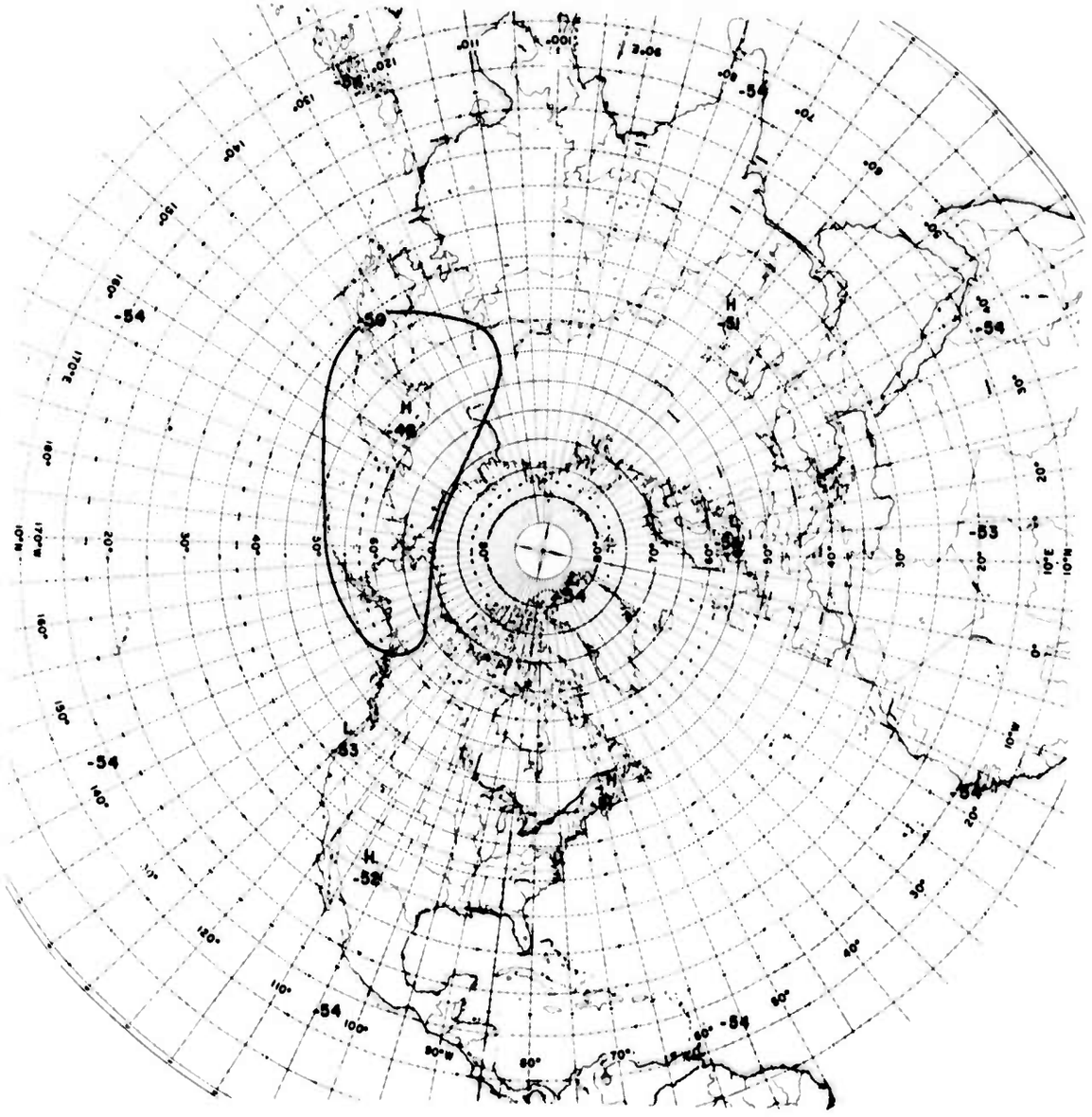
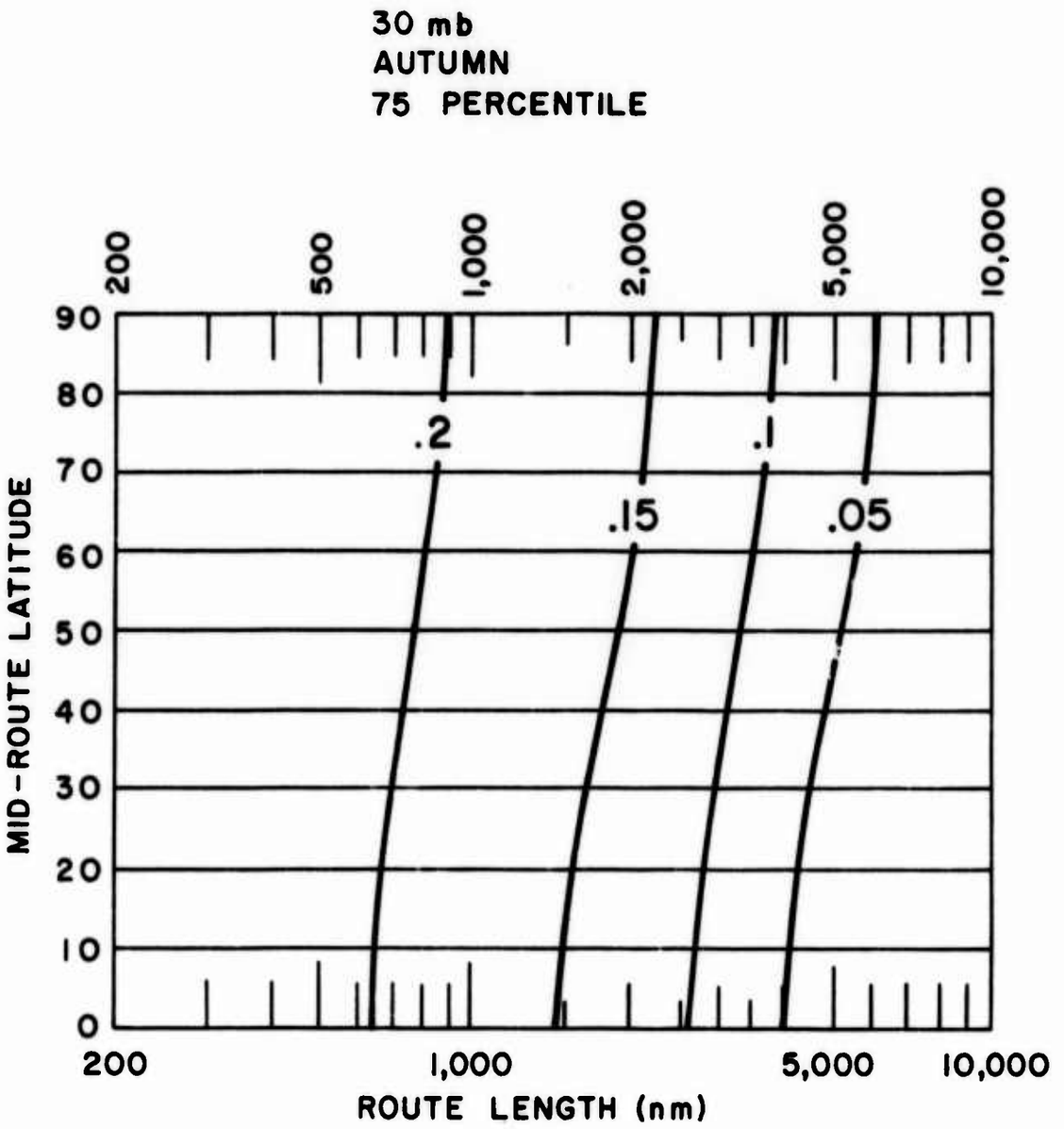


Plate 82. Temperature at 30 mb, in September, October, November, 75 Percentile



Graph 82. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

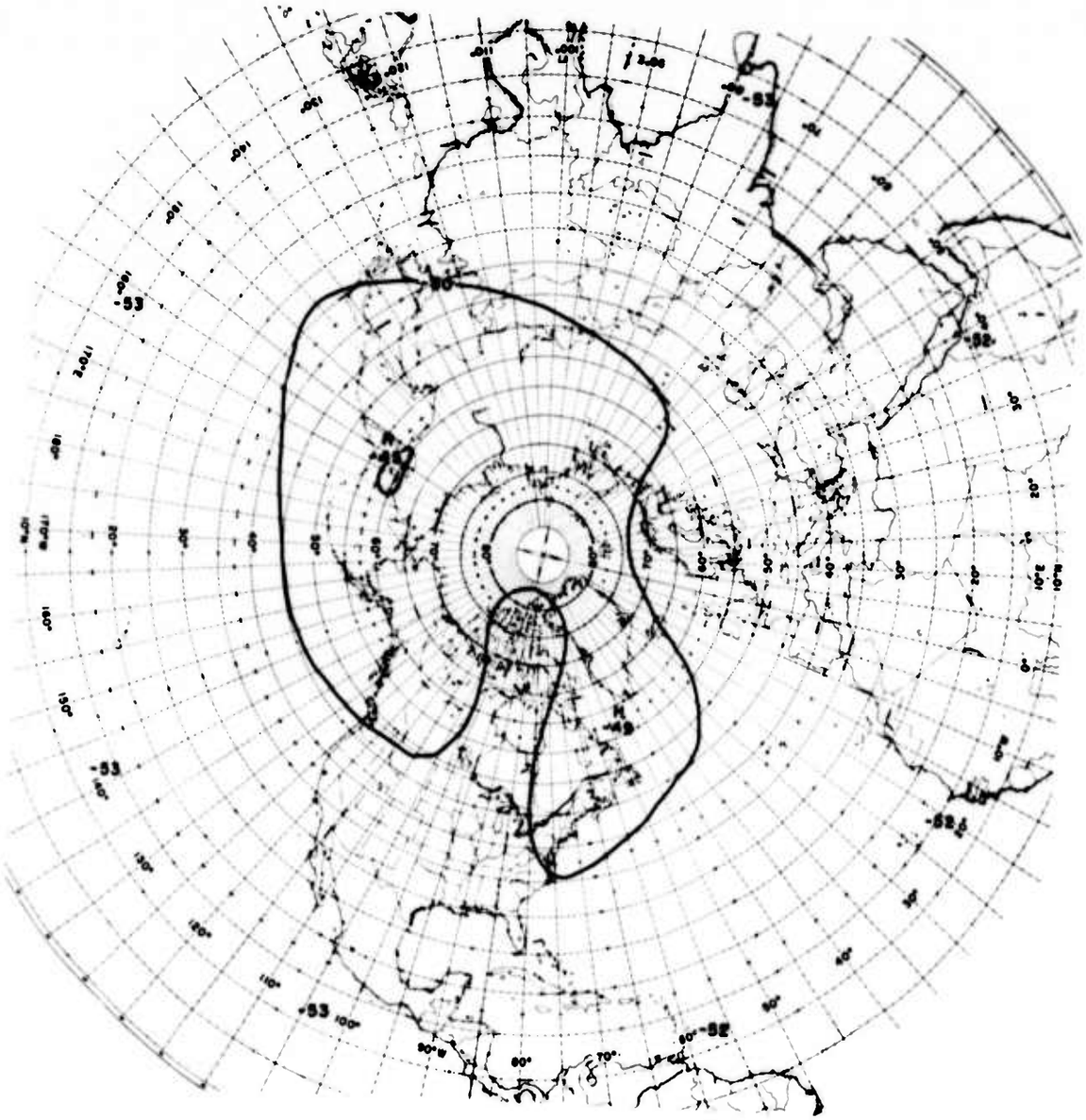
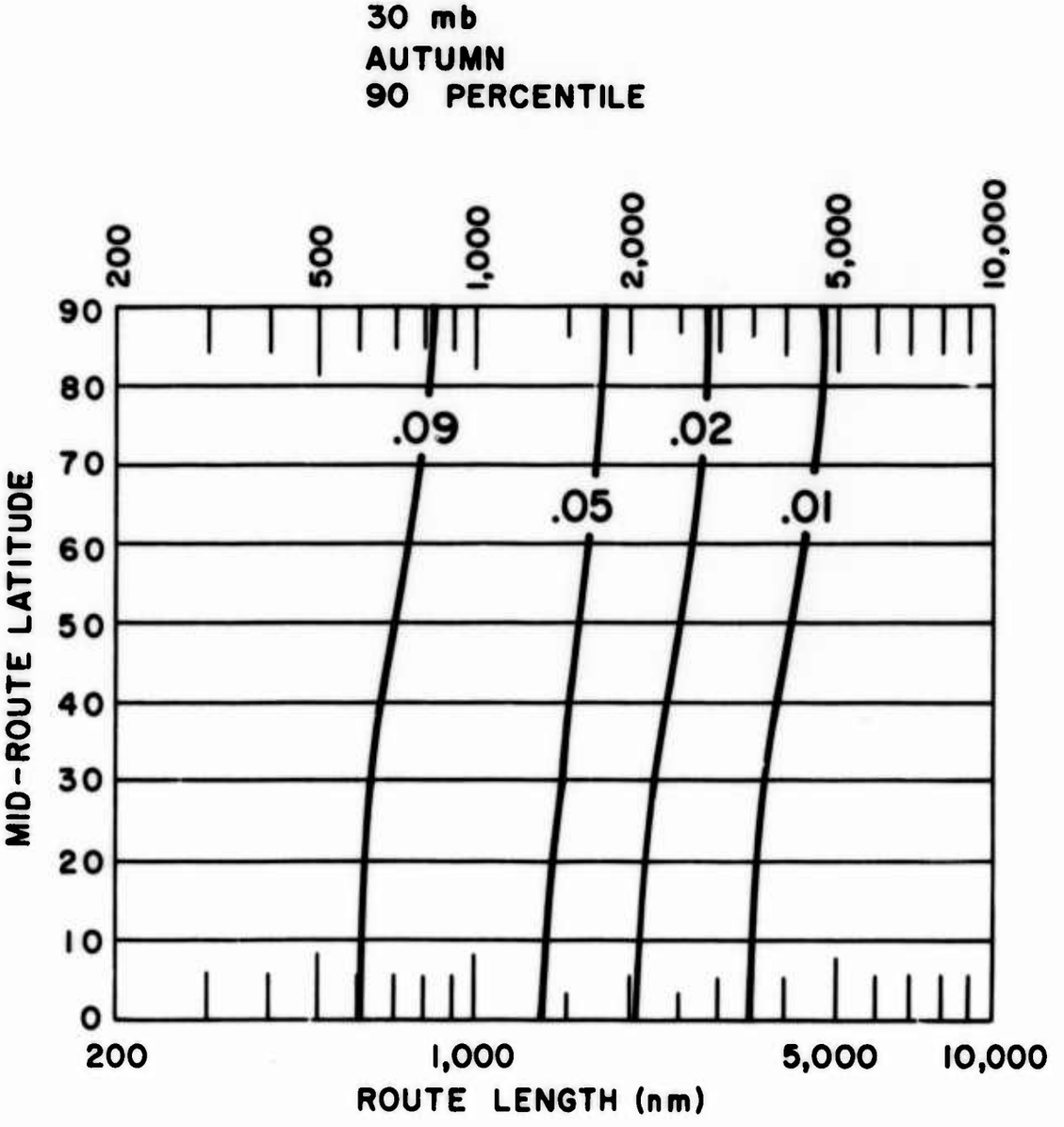


Plate 83. Temperature at 30 mb, in September, October, November, 90 Percentile



Graph 83. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

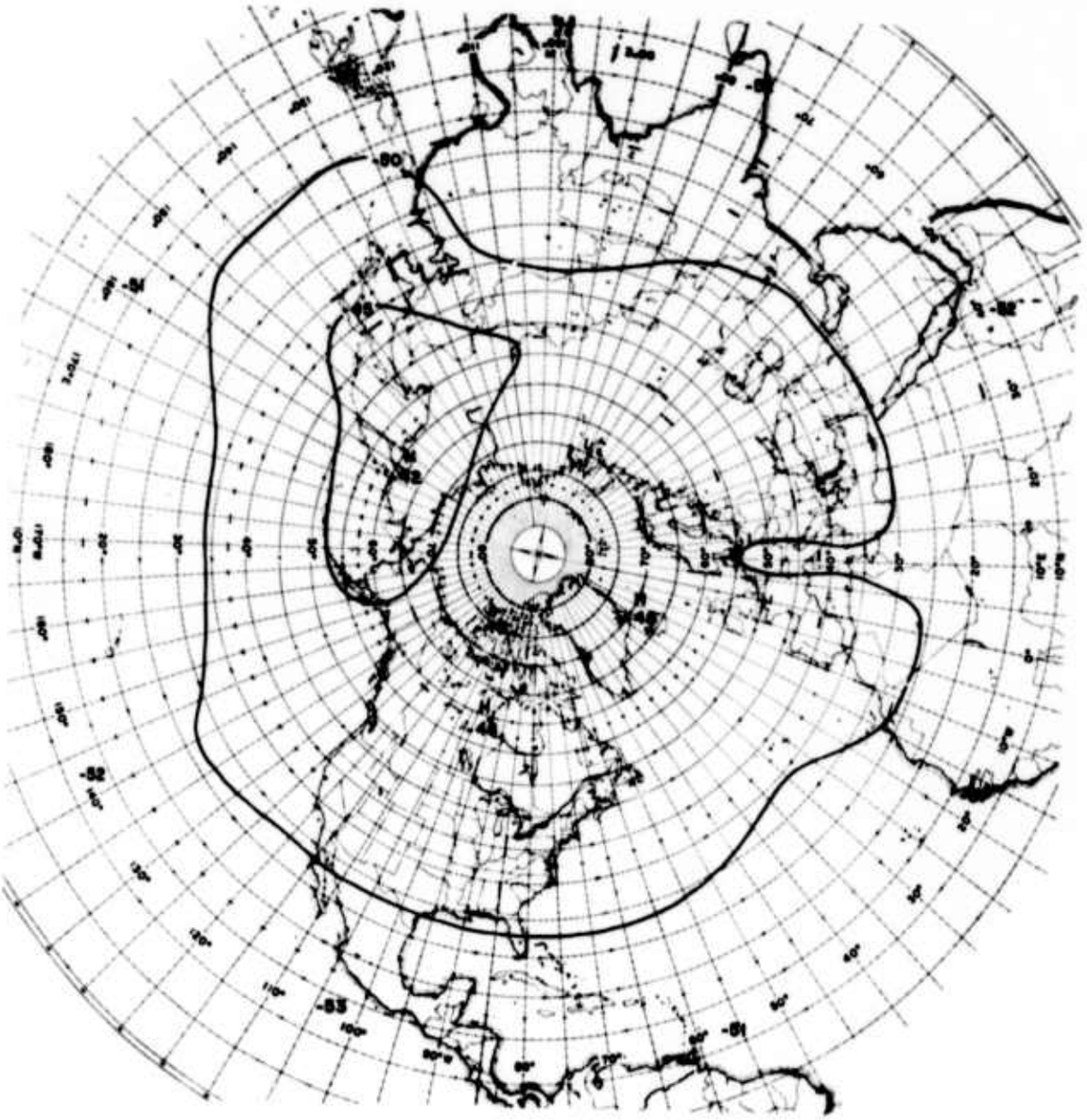
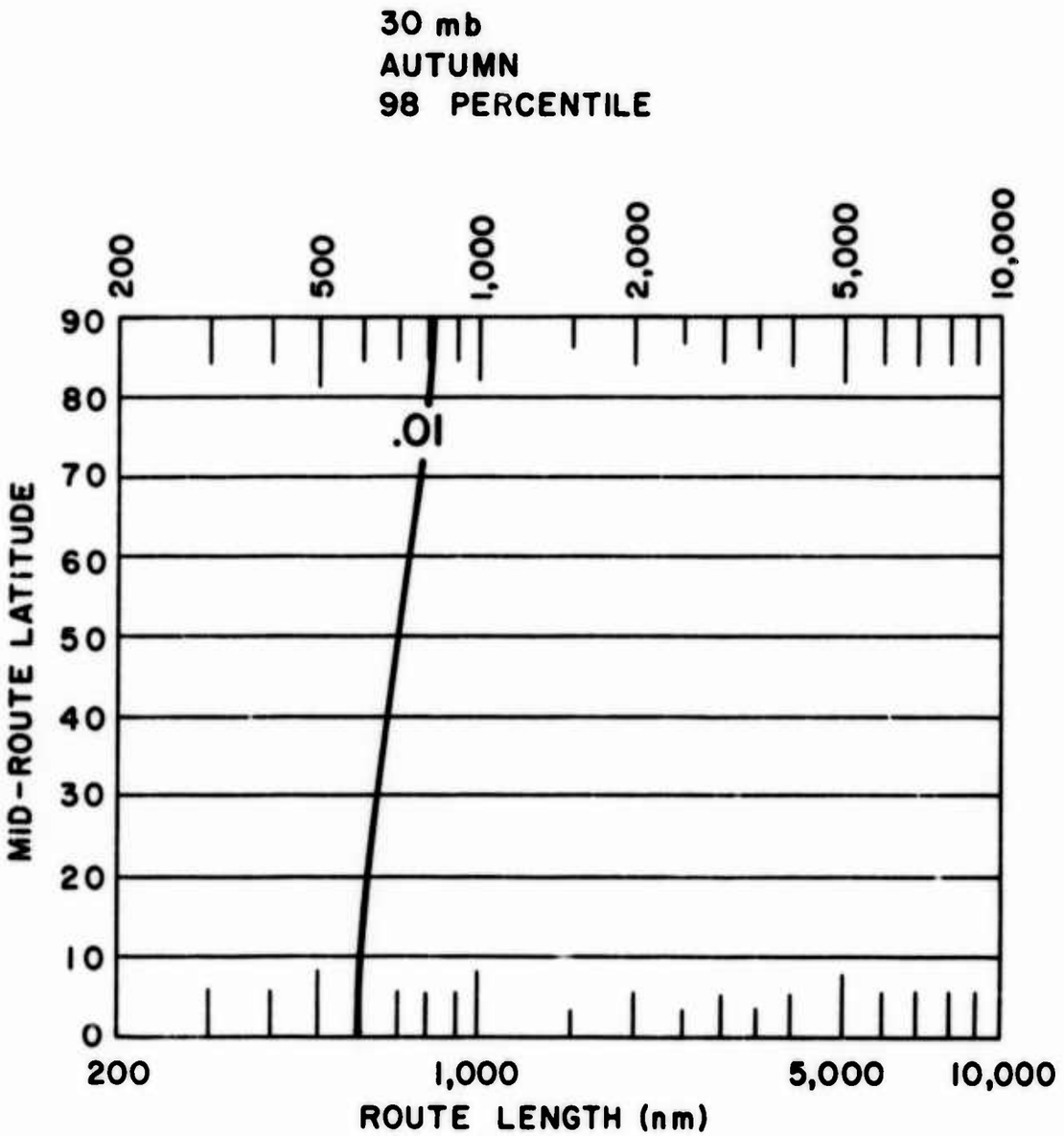


Plate 84. Temperature at 30 mb, in September, October, November, 98 Percentile



Graph 84. Probability of the Enroute Temperatures Exceeding the Temperatures on the Map, Opposite Page

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13. ABSTRACT

This atlas of the northern hemisphere temperature field at SST altitudes consists of 84 plates showing the isotherms at each of the constant-pressure levels, 100, 50, and 30 mb, standard altitudes of 53,000, 67,500 and 78,500 ft, respectively. For each level and season, there are seven maps giving the 2-, 10-, 25-, 50-, 75-, 90-, and 98-percentile temperatures. The charts were prepared from twice-daily grid-point data obtained from charts covering the area from the north pole to approximately 15°N for the period 1959 to 1968. Charts were computer analyzed by the Third Weather Wing, Air Weather Service, and made available by the National Weather Records Center, Asheville, N. C.

Since fuel consumption of supersonic aircraft is quite dependent upon temperature, each of the 84 plates is accompanied by a graph giving the probability that the temperatures on any route plotted on the map will equal or exceed the temperature shown on the map.

While the 84 maps are intended for straightforward informational use in SST flight-planning, there are many noteworthy features that are revealed by the percentile-type presentation. For example, the 96-percent range of temperature is roughly 7 to 10C° over the equator but is as great as 35C° over the far north in winter, a feature undoubtedly associated with occasional spectacular warmings in the polar stratosphere. But rarely does the temperature increase "explosively." The probability of a 10C° 24-hour increase of temperature is less than 10 percent anywhere, even from initially low temperatures. The probability of such an increase simultaneously over a wide area, 1000 nm or more, is negligible.

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